U.S. DEPARTMENT OF COMMERCE
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PB80-110893

Estech General Chemicals Corporation, Duette Mine; Manatee County, Florida. Resource Document Radiological Environment

W. Emmett Bolch, Gainesville, FL

Prepared for

Environmental Protection Agency, Atlanta, GA

Oct 79

PB80-110893

United States
Environmental Protection
Agency

Region 4
345 Courtland Street, NE
Atlanta, GA 30308

EPA 904/9-79-044G
October 1979

EPA

Environmental Impact Statement

DRAFT

Estech General Chemicals Corporation
Duette Mine
Manatee County, Florida

RADIOLOGICAL ENVIRONMENT

RESOURCE DOCUMENT

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BIBLIOGRAPHIC DATA SHEET	EPA 904/9-79-044G	PB80-110893

DEIS Estech General Chemicals Corporation, Duette Mine, Manatee County, Florida, Radiological Environment Resource Document

October, 1979

EIS Branch, Region IV, Atlanta, GA

Dr. W. Emmett Bolch, P.E.
4900 N.W. 19th Place
Gainesville, FL 32605

EIS Branch, U.S.EPA
345 Courtland St.
Atlanta, GA 30308

Draft EIS

The Draft Environmental Impact Statement for the Estech General Chemicals (formerly Swift Agricultural Chemical) Duette Mine is enclosed for your review and comment. The document has been prepared pursuant to Section 102 (2)(c) of the National Environmental Policy Act (NEPA) (Public Law 91-190) and applicable EPA regulations at 40 CFR Part 6.9. Thirteen volumes of resource document were also prepared. These resource documents comprise the detailed technical evaluations of the alternatives and the proposed action and contain supporting data related to the Draft EIS. While the Draft EIS is a complete document.

Volume G
Radiological Environment
Duette Mine
phosphate
NEPA

98

A05-A01

RADIOLOGICAL ENVIRONMENT

RESOURCE DOCUMENT

Draft Environmental Impact Statement

Swift Agricultural Chemicals Corporation
Duette Mine Site
Manatee County, Florida

October, 1979

Prepared For: U. S. Environmental Protection Agency
Region IV
345 Courtland Street, N.E.
Atlanta, GA 30308

Prepared By: Dr. W. Emmett Bolch, P.E.
4900 N.W. 19th Place
Gainesville, FL 32605

RADIOLOGICAL ENVIRONMENT

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NOTE:

Effective August 1, 1979, Swift Agricultural Chemicals Corporation changed its name to Estech General Chemicals Corporation.

The preparation of the Draft Environmental Impact Statement was substantially completed at the time of the name change. Therefore, the name of Swift Agricultural Chemicals Corporation (Swift) is used throughout the Draft Environmental Impact Statement and all attendant Resource Documents.

PART I - RADIOLOGICAL ENVIRONMENT BASELINE

1. INTRODUCTION

Radiation and radioactive materials occur everywhere in nature. Both existed long before man unlocked the secrets of the atom and entered the nuclear age. These naturally occurring radiations and radioactive materials can be altered and disturbed by man's technology. Almost any activity of man causes some alteration of either the quality or quantity of this natural radiation environment. The potential impact of any technologically enhanced radiation can only be understood if the existing radiological condition is clearly defined and understood.

The site is unaltered except for agricultural uses and the baseline radiological condition can be readily measured. The mining to the northeast in the west central Florida phosphate area has been extensively studied and can serve as a point of reference for this proposed site.

The following subsections will attempt to describe the background condition of the natural radiation environment in the absence of the proposed mining facilities. The only radionuclides having potential for significant impact are those of the uranium-238 decay series. The relative importance of the thorium-232 series will be addressed. The discussion will center upon the natural and disturbed condition of uranium-238 series radionuclides. Specific items to be covered include uranium associated with the phosphate, the uranium series including radium-226 and radon-222, radon progeny, terrestrial gamma radiation, airborne radioactivity, subsurface profiles of radioactivity, radium-226 in surface waters, and radium-226 in groundwaters.

2. RADIONUCLIDES IN PHOSPHATE DEPOSITS

Phosphate deposits are found all over the globe in rocks ranging in age from very young (less than 10,000 years old) to over 600 million years old. For perspective, U-238 has a half life of 4,500 million years. Mining operations in the west central Florida, Bone Valley district, have been continuous since 1888. Consequently, numerous studies have been undertaken of the radioactivity associated with these phosphate deposits.

2.1 Uranium - Phosphate Mineralogy

Apatite is by far the most common mineral of the phosphate group. Its general chemical formula may be written as $Ca_5(PO_4)_3(F,Cl,OH)$. Apatite deposits are widespread along a line extending from the North Carolina coast down into west central Florida. The phosphate content of these deposits varies greatly along this belt. Four economically attractive accumulations occur at approximately equal intervals along the line in North Carolina, South Carolina, northern Florida and west central Florida. Although the original formations from which these apatite deposits were derived have been obscured by extreme reworking, many similarities between them indicate a common origin. All of the most concentrated deposits seem to be of the same age, middle Miocene (approximately 20 to 25 million years old).

In order to understand the concentration of uranium, it is important to first understand the formation of the apatites. Many theories for the formation of apatites in Florida have been presented in the literature. Although they vary considerably in detail, most hypotheses recognize the association of organic matter with the phosphate deposits. It is generally agreed that apatite is deposited in areas of oceanic

upwelling. During the middle Miocene, the regional geologic relationships of the southeastern United States were such that the required upwelling was occurring along the coast from North Carolina to Florida. The upwelling was caused by the meeting of the cold, southward flowing Labrador current and the warm, northerly Gulf Stream. This process has been termed "dynamic upwelling". The interaction between these currents produced turbulent mixing of the cold, nutrient laden Labrador waters with the warm Gulf Stream. This environment, being geochemically conducive to the precipitation of phosphate from the sea water, produced the primary apatite deposits. Once deposited, the apatite underwent extreme reworking due to the repeated rise and fall of sea level that occurred during later ages associated with glaciation of larger areas of the earth. By this mechanism the deposits were locally concentrated in areas of topographic depression. The reworking processes also caused chemical alterations resulting in secondary phosphate minerals which are generally more concentrated than the primary apatites from which they were derived.

Primary apatite contains only trace amounts of uranium, generally on the order of a few thousands or hundredths of one percent. However, most other natural materials contain at most a few parts per million and normally only one or two parts per billion. Thus, apatite serves as a natural concentrator of uranium. Sedimentary apatite typically contains from 0.005 to 0.02 percent uranium. When submitted to extensive marine reworking the uranium content of these apatites may be increased to as much as 0.1 percent. Therefore, the association of uranium with Florida phosphate deposits is to be expected.

Cathcart (Ca56) and Altshuler, et al. (At56) have published detailed papers on the west central Florida land pebble deposits of the Bone Valley Formation and its relationship to uranium. Cathcart found the highest uranium concentrations to be at the base of the leached zone and associated with the calcium phosphate minerals. Uranium in the matrix was found to occur almost exclusively with apatite. Altshuler drew similar conclusions.

2.2 West Central Florida Uranium

Uranium is found in most rocks and soils. Typical concentrations range from 4 ppm in granite and 3 ppm in acid igneous rocks to 0.6 ppm and 0.03 ppm in basic and ultrabasic igneous rocks, respectively. Limestones and other sedimentary rocks contain about 1.2 ppm uranium. In contrast, the important uranium reserves of the Colorado Plateau region averages about 2,100 ppm U_3O_8 or 1,800 ppm U.

The uranium content of the phosphate matrix of west central Florida may average 120 ppm. Individual samples of selected strata may exceed 400 ppm U. It is important to re-emphasize that the uranium is not confined to the phosphate matrix, but is ubiquitous with measurable concentrations both above and below the mineable matrix. The exact nature of the distribution will be discussed in a later sub-section.

In general, the upper portion of the Bone Valley Formation has been leached, altered to aluminum phosphates, and enriched in uranium through groundwater processes. This zone is widespread, though discontinuous, throught the west central Florida phosphate district and averages 6 to 7 feet in thickness. Overall uranium content in this aluminum phosphate zone is approximately 50 percent higher than the phosphate ore section underlying it.

At the Duette Mine site, however, the prospect data indicates a very thin to nonexistent leach zone. The matrix at the site averages 23 ppm U.

Uranium itself is potentially a recoverable resource. Extraction from phosphoric acid is both practical and economically attractive, since the mining processing and leaching costs have been borne by the primary product. Several companies now have associated uranium recovery operations. Extraction from phosphate pebble and concentrate is not feasible at this time.

Uranium as a mineral is normally reported in ppm. The radiological hazard is associated with individual nuclides and the decay products. Uranium, in nature, consists of three isotopes having mass numbers of 234, 235, and 238. The latter nuclide, U-238, is the parent of a long decay series and accounts for 99.28% of all mineral uranium by weight. Thus, the other uranium species are of little importance except for special applications, such as the U-235 used as nuclear fuel. The specific activity of U-238 is 0.33×10^6 pCi/g. Thus 100 ppm U converts to a radioactivity measurement for U-238 of 33 pCi/g. A picocurie (pCi or 10^{-12} curies) is 2.22 nuclear disintegrations per minute. Each radioactive daughter in equilibium with the 33 pCi/g U-238 parent will also be at a radioactivity level of 33 pCi/g.

2.3 Thorium and Radium-228

The Primary Drinking Water Regulation - Radioactivity published by EPA in July of 1976 limits the total radium in water to 5 pCi/l. Both radium-226 and radium-228 can contribute to this 5 pCi/l limit. Radium-228 is the first daughter of the naturally occurring thorium-232 series and is not associated with the uranium-238 discussed in the previous and following sub-sections. Concern has been expressed, however, for the potential contamination of waters in west central Florida with radium-228. The purpose of this sub-section is to set the proper perspective for this radionuclide.

The screening guidelines and procedures suggested in the drinking water regulation and the statement of basis and purpose that accompanied the initial publication of the proposed radium in water standard, both suggested certain relationships between radium-228 and radium-226. First, it can be shown using continuous ingestion and an exponeutial retention model that product of the effective half-life and effective energy is nearly equal for both radionuclides. This product is proportional for the average bone dose. Therefore, each should be considered as having equal toxicity to man.

Radium-228 measurements are difficult and therefore are extremely sparse in the literature. None were found in a survey of Florida data on radioactivity. Under normal circumstances, the radium-228 content of food, water, and human tissue is from one-forth to one-half of the radium-226 content (UNSCEAR 1966). Eisenbud (1973) states that radium-228 frequently occurs in water in approximately a 1:1 ratio to radium-226, but that radium-226 is of special interest in those areas of the world noted for abnormally high concentrations of soil thorium.

The drinking water regulation allows certain screening procedures to be altered in areas where radium-228 is known to have limited impact. Thus, the important question is whether the west central Florida area contains thorium in sufficiant concentrations to make radium-228 a true concern?

In general, the world average concentration of thorium in various igneous rocks, limestones and sedimentary rocks is about three times that of uranium (ppm basis). However, since thorium-232 has a specific activity about one-third that of uranium-238, the radioactivity of the two radionuclides in many soils and rocks is more nearly 1:1 (pCi/g basis). Specific data on thorium-232 in Florida phosphate associated media is found in an EPA technical note (EPA 75) and in direct correspondence with several phosphate companies after EPA reconnaissance trips in 1974. (Windham 1975). These data indicate the U/Th ratio in terms of pCi/g per pCi/g to be about 90 for marketable rock, 30 for clays, 60 for air particulate samples, 180 for untreated process water, and 80 for outfall water after double liming. Any single ratio may have considerable error since the low values for observed thorium concentrations had high associated errors ($\pm$ 30%). It is evident however, that on an activity basis, the west central Florida environment is different from the world average ratios of U to Th. Thorium contents in the phosphate areas are nearly two orders of magnitude lower than the world averages. Radium-228, the daughter of thorium-232, should follow the same trend. For example, media such as a west central Florida groundwater that contains 1 pCi/l radium-226 (an easily measured level) would be expected to have radium-228 levels below 0.01 pCi/l. The USGS analytical procedure (R-1142-76) for radium-228 indicates the lower limit of detection

is about 1 pCi/l $\pm$ 20%. Stated in other terms, the radium-228 in west central Florida water will be undetectable when the radium-226 levels exceed the drinking water standard of 5 pCi/l.

3. THE URANIUM SERIES

In order to understand the hazard posed by disturbing the location and both the physical and chemical state of the natural radioactivity present in the phosphate, a clear understanding of the complexities of the uranium decay series is required. The following discussion will define terms and subgroups of the series in relationship to the proposed mine and beneficiation facility.

3.1 Uranium Equilibrium

In the uranium-238 series, decay proceeds serially through 13 intermediate radionuclides, called daughters, to a stable endpoint of the element lead with a mass number of 206. The radionuclides in the series are diagrammed in Figure 3.1-1. Vertical displacements in Figure 3.1-1 involve alpha particle emissions. Diagonal displacements represent beta particle emissions and many of the particulate emissions are accompanied by gamma ray emissions.

The rate at which a radioactive nuclide will disintegrate is related to the number of radioactive atoms present and its half-life. A given number of disintegrations per second has been given a unit: 3.7×10^{10} dps equals one Curie. Most of the discussions in this report will deal with a much smaller unit: the picocurie (pCi) or 10^{-12} curies. For any particular daughter radionuclide in the series, there is a rate of production via decay of its immediate parent and a rate of loss via decay into the next daughter. The nature of the mathematics is such that a condition of equilibrium is achieved if the entire series is contained in a "sealed" location over a long period of time. In other words, a geological sample containing 100 pCi of U-238 may also contain 100 pCi of Th-234, 100 pCi of Pa-234, 100 pCi of U-234, and so on,

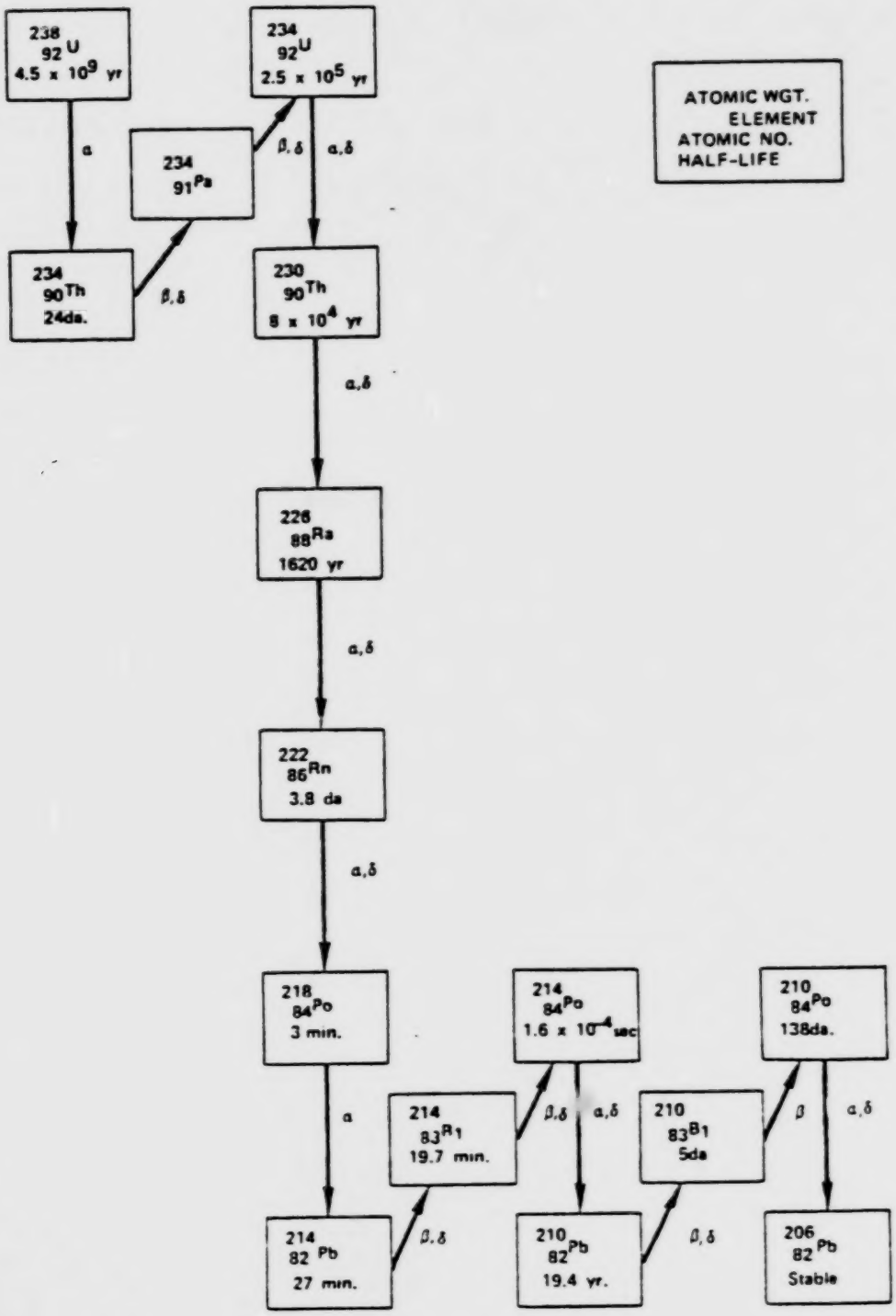


Figure 3.1-1 Uranium-238 Decay Series

through 100 pCi of Po-210. Habaski suggests that in sedimentary phosphates, uranium exists in radioactive equilibrium with all its decay products (Habaski 1966). Equilibrium is maintained only if the materials are undisturbed. Natural phenomena could produce such a disturbance.

Differential dissolution of specific materials by groundwaters would also disturb the equilibrium; however since uranium and radium are normally present in rocks and soil at equilibrium activity levels, the solubility of each and the intermediates must all be extremely low. The presence of both uranium and radium in high concentrations and in equilibrium within the leached zone, when present, is a strong indication of the insolubility of these radionuclides and their intermediates.

3.2 Radium

Radium-226 is the fifth decay product in the U-238 series. It is a divalent cation with a long physical half-life (1620 yr.). Figure 3.2-1 illustrates the equilibrium re-established from separated radium. This behavior of this series is important to the hazard evaluation and comprises the primary basis for the detection of radium-226 either by quantification of radon-222 alpha decays or of lead-214 and bismuth-214 gamma emissions.

Radium-226 is of particular interest in regard to human exposure. Radium is chemically similar to calcium and tends to be incorporated biologically in the same way as calcium. Radium replacement is clearly demonstrated by the high radium-226 concentrations found in the gypsum($CaSO_4$ $2H_2O$). Radium-226 may be ingested through drinking water in which the material has been dissolved. A less probable pathway is via uptake into foods grown on soils containing radium-226.

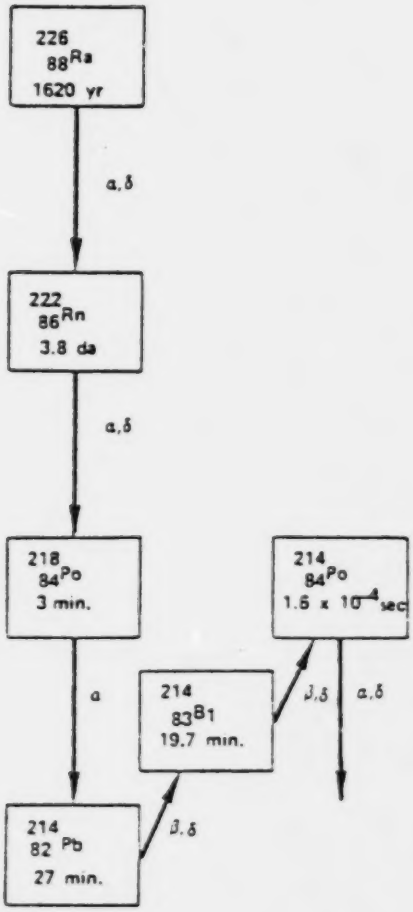


Figure 3.2-1 Equilibrium established 20 days after chemical separation of radium

In addition to the drinking water regulations for radium-226 and radium-228, effluent guidelines for National Pollutant Discharge Elimination System (NPDES) permits for fertilizer and phosphate manufacturing were issued by EPA in 1975. The effluent limitation of 9 pCi/l total radium was recommended.

Radium, like uranium, is ubitiqous in nature and is found in almost every environmental media. The average daily intake per person in the USA has been estimated to be 1.4 pCi (United Nations 1972).

3.3 Radon Progeny

The radium-226 decay scheme equilibrium, is highly dependent upon the mobility of the radon-222, an inert gas. The last four radionuclides in the decay scheme shown in Figure 3.2-1 are known as radon progeny (or daughters of radon). There is normally a potential for the transport of the noble gas radon-222 away from the location of its radium-226 parent. Depending on the mineralogy and the physical nature of the deposit, radon-222 could diffuse to the void space and begin diffusive transport to areas of lower concentration, usually upward toward the atmosphere. In this case, the overall equilibrium of the series would be disturbed if significant radon escapes the general area of its production.

In the natural unmined state, most of the radon-222 produced in a phosphate matrix would not escape the media. Mining and beneficiation alters the location and physical condition of the radium-226 bearing minerals and may increase the probability that radon-222 will be able to diffuse from the site at which it was created. Figure 3.3-1 diagrams this potential transport.

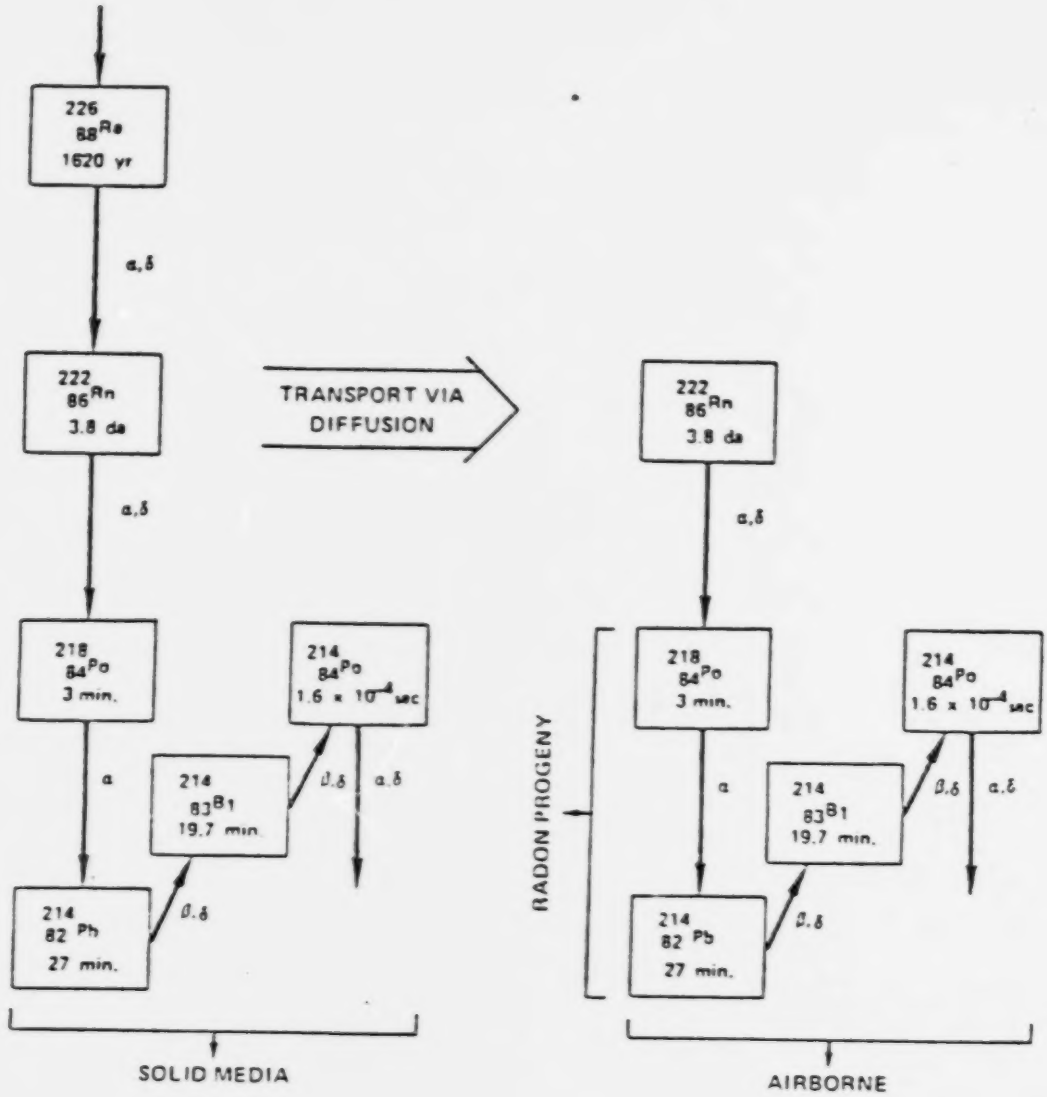


Figure 3.3-1 Representation of the production of atmospheric radon and its decay products

The ability for the radon to move from the mineral or media into the void space of the soil is defined by a term called emanating power, E, usually expressed as a percent. The general expression defining the term for a closed unit volume would be:

$$E = \frac{\text{pCi/gram radon-222 in the void space}}{\text{pCi/gram radon-222 in the total sample}} \quad 100\%$$

Typical values for emanating power in Florida soils and phosphate related materials range from a few percent to 30%. Without specific knowledge about a particular media, a typical value would be 18%. Thus, in most case, 82% of the radon-222 produced remains with the solid structure, 18% is capable of transport, and less will actually gain access to the atmosphere. Any concentration gradient for radon will induce molecular diffusion of this "emanated" radon to the surface of the soil. The rate of movement through the soil-air interface will be in units of pCi/m^2s and is termed "radon flux". This parameter is considered an important screening unit for testing reclaimed lands. Guidance for evaluation of undeveloped phosphate land will be proposed by EPA at a later time (EPA, 1979).

Radon flux from the soil will contribute to be airborne radioactivity. The airborne radon-222, whether in the open air, near industrial sources, or inside homes, will decay and an approach to equilibrium between the next four daughters (polonium-218, lead-214, bismuth-214, and polonium-214) will begin. These four radionuclides are known as the radon progeny.

3.4 Other Radionuclides

There is one other way to view the uranium decay series. The radionuclides uranium-238, uranium-234, thorium-230, radium-226 and polonium-210 are all long-lived radionuclides that could become airborne in dusty operations or by other mechanisms. Individual airborne radionuclides

are measured in terms of concentration in air, for example pCi/m^3. The airborne radioactivity limit for each radionuclide is expressed in terms of a maximum permissible concentration (MPC_a), i.e., that concentration which, under continous exposure, would just result in a maximum permissible dose to an appropriate critical organ. Every radionuclide has a unique associated MPC_a value. However, determining specific concentrations of individual alpha emitters in a mixed population is most difficult and gross alpha screening at an appropriate level is an accepted alternative.

4. SUBSURFACE RADIOACTIVITY

Since the origin of the uranium in the deposits is similar to the phosphate, it should be evident that the concentration of uranium and thus radium-226 should follow the concentrations of phosphate: a low concentration in the overburden and a high concentration in the matrix. The actual distribution is slightly different.

4.1 Radium-226 and Uranium Profiles

In the west central Florida mining regions, the radioactivity is low at the surface, increases gradually and then more rapidly with depth and is most concentrated in or just above the matrix. Figure 4.1-1 represents a composite generalized profile of radium content with depth from the surface to the top of the matrix in undisturbed phosphate lands as constructed by Roessler, (February 1977) from various profiles. Uranium and radium are in general equilibrium. If present, the leached zone is usually marked by high radioactivity.

The distribution of radioactivity within the matrix is variable. A west central Florida site with a leached zone is shown in Figure 4.1-2.

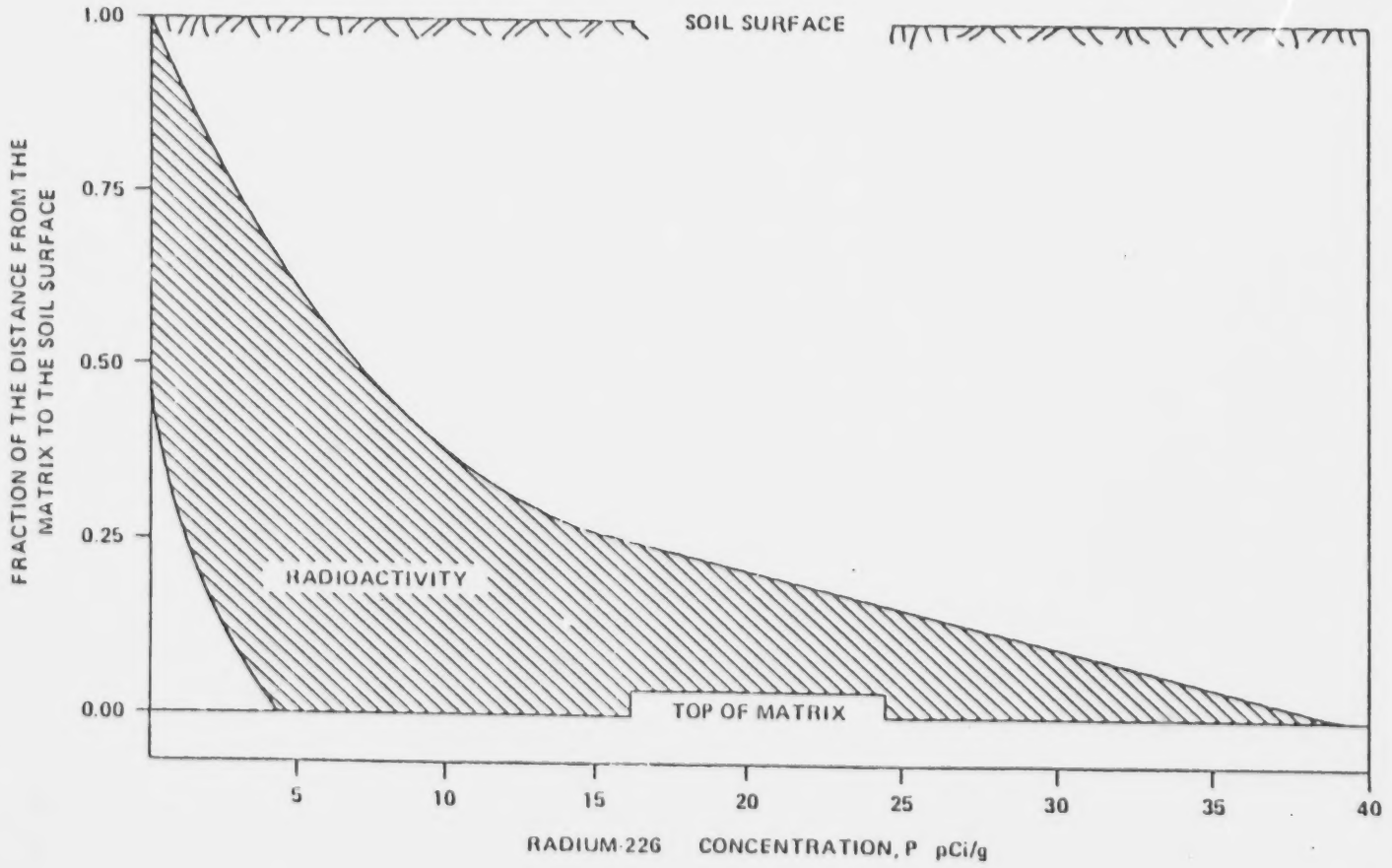


Figure 4.1-1 Normalized radium profile for unmined phosphate lands

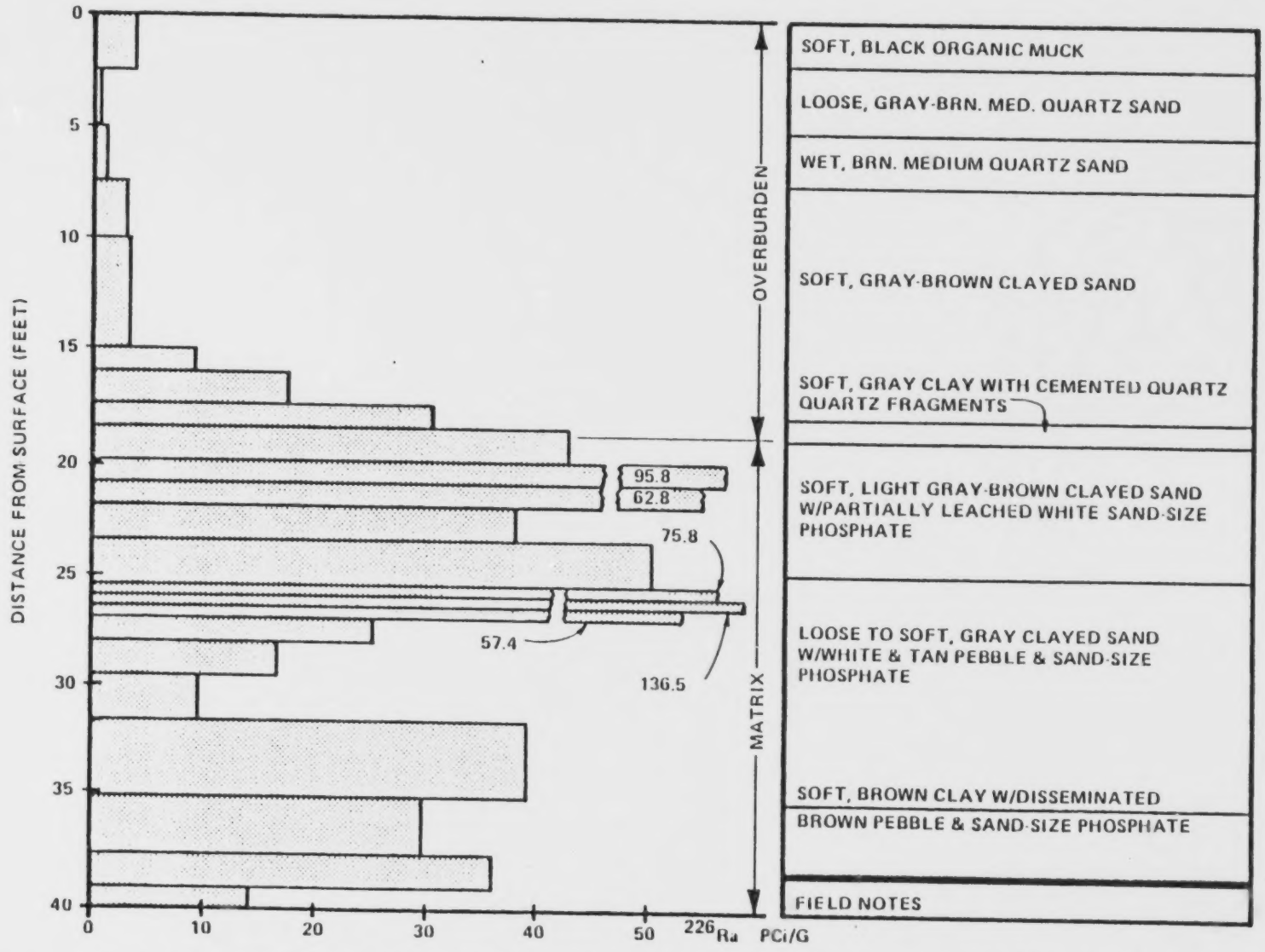


Figure 4.1-2 Profile of radioactivity in central Florida phosphate region high leach zone

Profiles with either normal, high or low leach zone indicate a similar pattern and most indicate a slight decrease in the concentration of radium-226 with depth within the matrix. The profiles also indicate a wide variation with small distances within the matrix. Composite samples will yield lower concentrations than small individual fractions. (Roessler et al., Feb. 1977)

At the Duette site, eight cores were analyzed for radium-226 and uranium. Four to six samples were from each core were composited over a depth range. Figure 4.1-3 shows the distribution of the radium-226 samples versus depth for the 38 samples plus two additional pasture land surface samples from the site. Since samples were composited over a range of depths up to 10-feet, some details (thin higher concentration strata) may be obscured. However, the pattern of low surface concentrations, increasing concentrations within the overburden, peak concentrations near the top of the matrix, and somewhat decreasing concentrations with depth within the matrix is repeated at the Duette site.

Uranium analysis were performed on all core samples. All concentrations (pCi/g) were approximately equal to those of the radium-226, but with some indication of less radium than would be predicted from uranium decay equilibrium. Roessler et al. (1978) observed a radium-226/uranium-228 ratio of less than unity.

Table 4.1-A compares the subsurface radioactivity data for the Duette site against the west central Florida data Roessler et al (1978). Note that geometric means are used, even for small numbers of samples. Two swamp area samples from the site, were not included in the surface soil calculations.

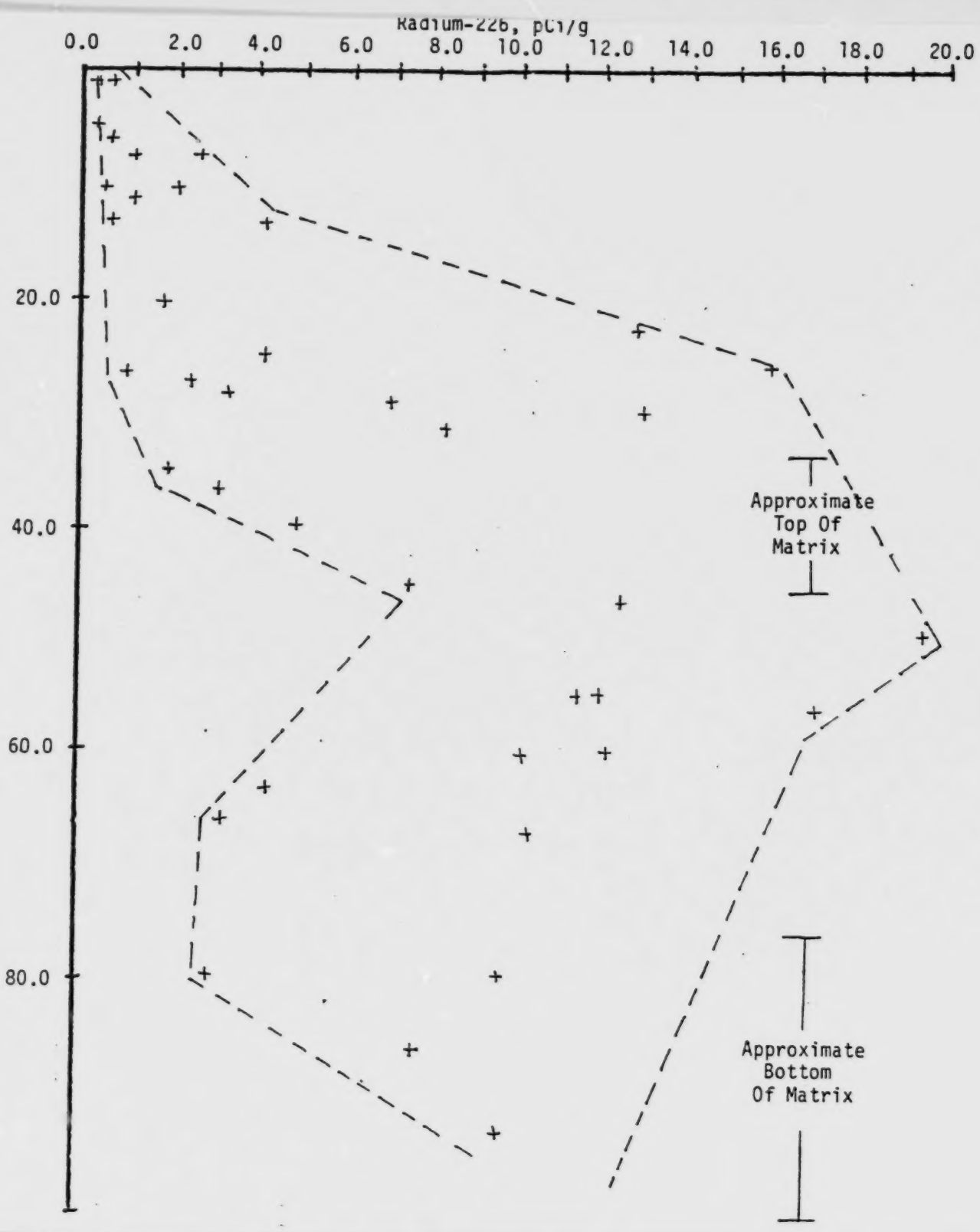


FIGURE 4.1-3

PROFILE OF RADIOACTIVITY AT THE DUETTE SITE

Source: W. E. Bolch, Ph.D.

U.S. EPA - REGION IV
DRAFT ENVIRONMENTAL IMPACT STATEMENT FOR SWIFT AGRICULTURAL CHEMICALS CORPORATION PROPOSED DUETTE MINE
MANATEE COUNTY, FLORIDA

Table 4.1-A Radium-226 Concentrations in Topsoil, Overburden, Leached Zone, and Matrix of Mining Lands

Material Type	Duette Site Radium-226 Concentration pCi/g	W. Central Florida Radium-226 Concentration pCi/g
Surface Soil (0-30 cm)		
Average	0.5	0.5
(Range of site means)	--------	(0.2-3.8)
(Range of individual samples)	(0.41-0.52)	(0.2-3.8)
Number of sites (samples)	(2)	5
Overburden (Surface to Matrix)		
Average	1.5	2.5
(Range of site means)	--------	(0.5-7.2)
(Range of individual samples)	(0.48-12.9)	(0.2-30.6)
Number of sites (samples)	(14)	8
Matrix		
Average	5.1	25.9
(Range of site means)	--------	(13.2-84.2)
(Range of individual samples)	(3.1-9.2)	(6.0-136.5)
Number of sites (samples)	(7)	13

Average = geometric mean of site means.

These analyses suggest that the radium-226 concentration in Duette site top soil (normally the first six to 12 inches) averages 0.5 pCi/g, the same as the west central Florida top soil. Both values are lower than the 0.7 pCi/g average radium-226 concentration given by Eisenbud for 23 specimens of rock and soil in the USA (Eisenbud 1973).

The overburden data for the Duette site when compared to the west central Florida data of Roessler et al. (1978) indicate that the Duette site has about 40% less radioactivity. Some of the indicated reduction may be due to the larger depths composited but this would not account for the total difference. Note that the range of site means for the current mining district in west central Florida is about the same as the Duette site sample range. However, the Duette site has a much thicker overburden and the lower mean may not be unexpected.

The data on the matrix at the proposed site versus the summary for west central Florida reinforce the difference between the two locations. Both the averages and upper ranges of individual samples indicate a matrix concentration of radium-226 at the Duette site that is much lower than the matrix of the west central Florida mining district. Four additional measurements on the Duette matrix were taken when typical matrix material was subjected to pilot plant beneficiation. The four samples yielded a geometric mean of 8.5 pCi/g. This value is higher than the 5.1 pCi/g shown in Table 4.1-A, but within the same range. If all matrix data are grouped, the geometric mean is 6.1 pCi/g.

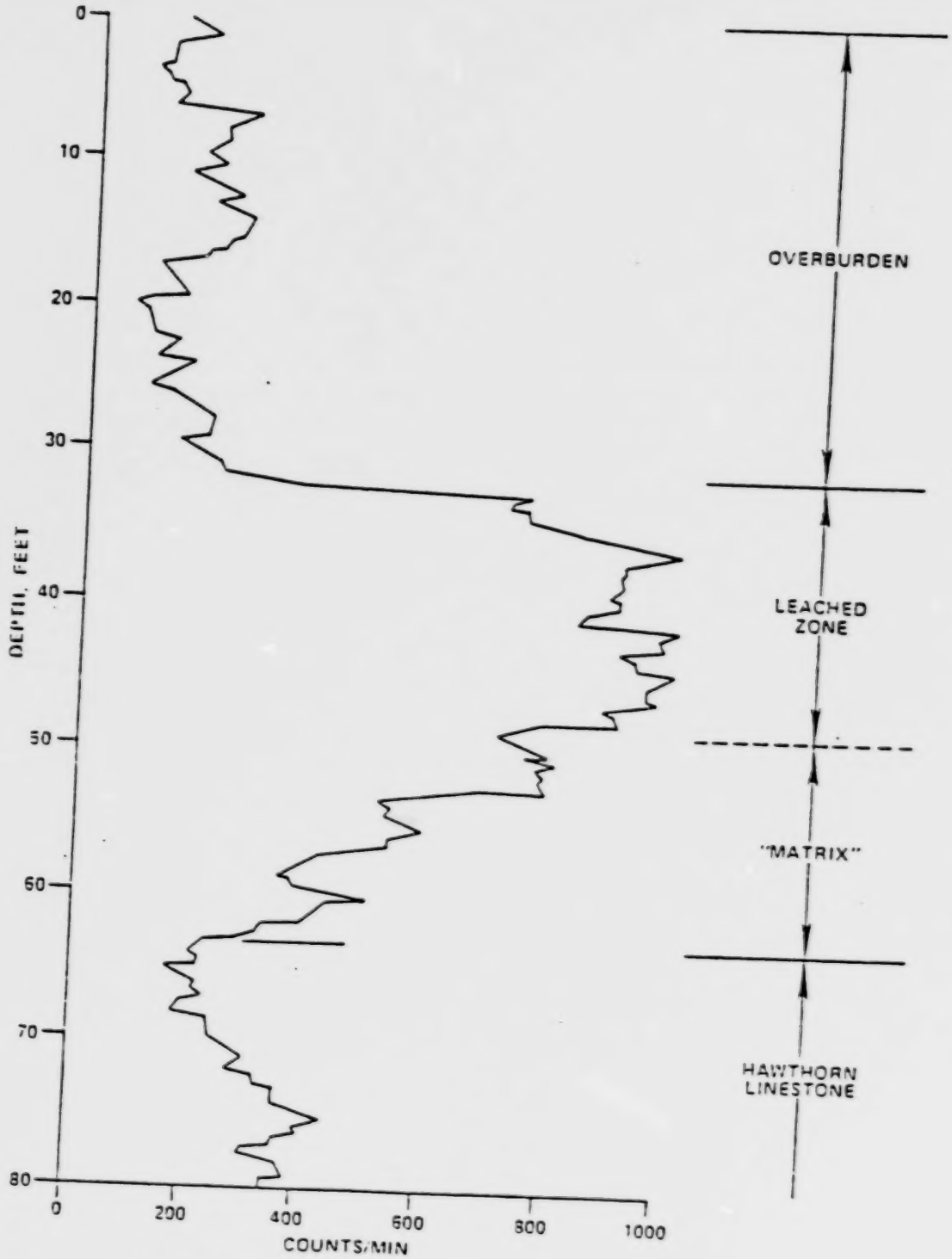
4.2 Gamma Logs

Since a major fraction of the gamma radiation level in Florida is related to the uranium series, and especially radium-226, radon-222 and radon progeny, gamma logs of wells should also reflect the radium-226

profiles shown in Figures 4.1-1, 4.1-2, and 4.1-3.

The location of the gamma log shown in Figure 4.2-1 within the west central Florida land pebble district is unknown, yet the similarity to the radium profiles is striking. The gamma well log from the Duette site is shown in Figure 4.2-2. Here the depth has been extended to 1,000 feet. The characteristics of the lower depths have been often ignored and yet these features play an important role in the consideration of the possibility of contamination of groundwaters. The existence of rather enormous quantities of radioactivity between the mined fraction and the deep aquifers has not been adequately addressed in the literature. The gamma activity in Figure 4.2-2 (also relative radium concentration) increases nearly linearly with depth to approximately 35 feet where the rate sharply increases as does the phosphate level (Guyton 1976) and then falls gradually to around the 100-foot mark. The mineable matrix at this core lies between the 35-foot and the 90-foot levels. Since the origin of the matrix is known to be linked to the Hawthorn formation, the entire Hawthorn strata, here approximately 300 feet thick, would be expected to also contain uranium and its daughters because of its geologic history. The gamma log dramatically illustrates this fact. The activity begins to increase again below the matrix and reaches a peak at about the 200-foot level. It then decreases beyond the 350 to 400 foot level and falls off slowly with depth. These increases and decreases generally correlate well with increases and decreases in phosphate content (Guyton 1976).

By a technique of graphical integration of this gamma log, it is possible to relate the fraction of radioactivity occurring between any depths. The numbers shown to the right of the log in Figure 4.2-2 are the percent of area beneath the curve (relative radioactivity) occurring at 100-foot



"MATRIX IS THE LAYER MINED. LOG MADE BY THE U.S. GEOLOGICAL SURVEY

Figure 4.2-1 Gamma-ray log of an exploratory hole in the Florida land pebble phosphate deposit

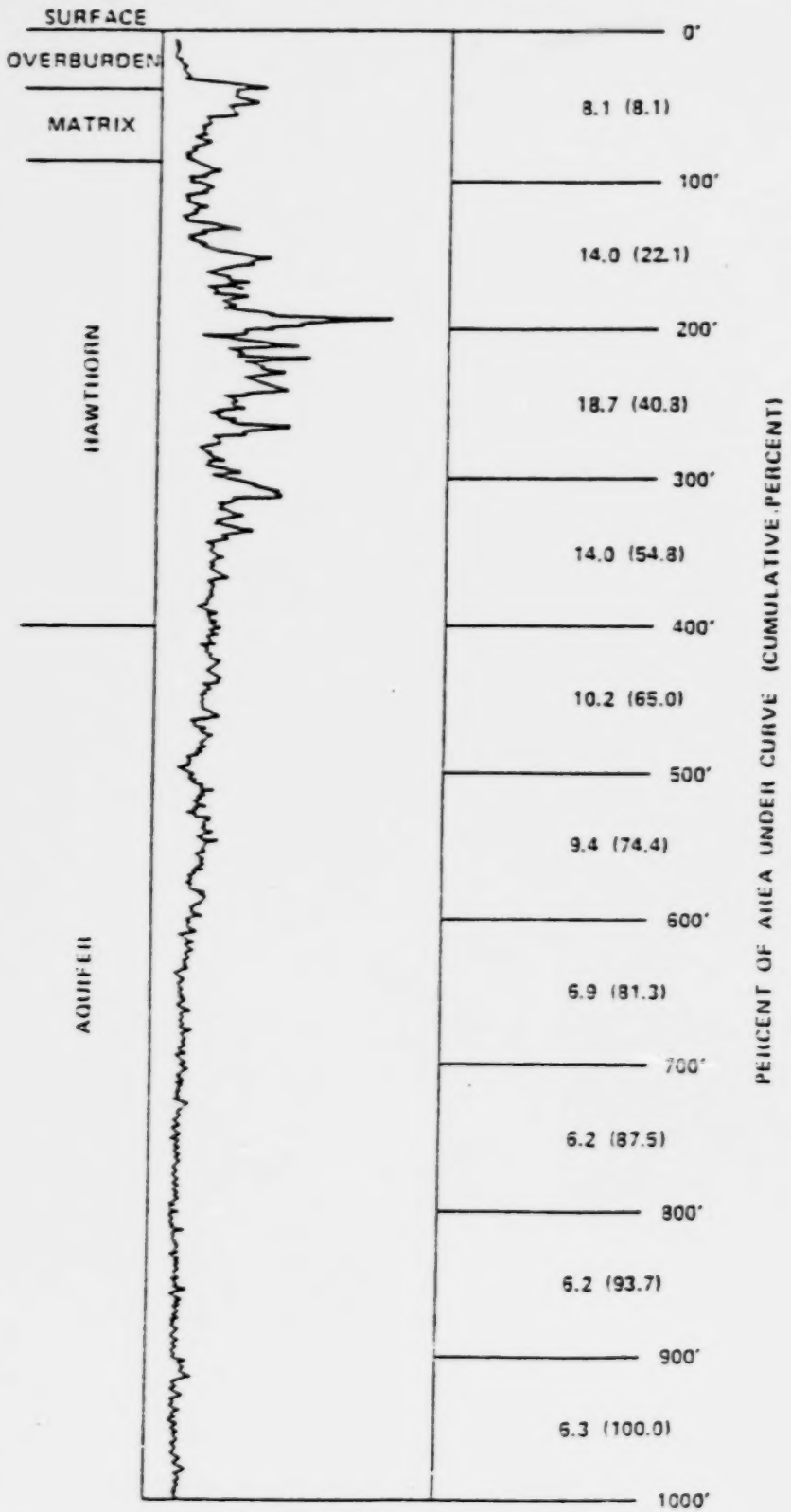


Figure 4.2-2 Gamma-ray log of a deep well on the Duette Site

intervals from the surface to 1000 feet using the total area under the curve as 100 percent.

By this method it is readily apparent that the combination of both the overburden and the mineable matrix represents only 8.1 percent of the total activity in the 1000-foot column. The remaining Hawthorn formation from which the matrix was derived, represents about 50 percent of the total radioactivity within 1000-foot column. Note that the primary aquifer lies below the Hawthorn formation.

Radium-226 in the Floridian aquifer underlying the Hawthorn formation has been of much interest. The relationship of the deep aquifer radium and the high radioactivity in the total Hawthorn is not understood, however, current levels of radium in the aquifer may be more closely related to the lower Hawthorn than the matrix some 300 feet above. It should be noted that monitor wells often draw water from locations indicating high gamma log activities. Because of existence of higher radium contents in strata from which water is drawn for monitoring purpose, it may be exceedingly difficult to determine the existence of radium-226 transport from other locations, in either the vertical or horizontal direction.

5. TERRESTRIAL GAMMA RADIATION

This section will review the various background gamma radiation sources with particular emphasis on comparing the proposed site to averages for the continental United State and general levels within the west central Florida. Table 5-A summarizes the estimated average background dose to United States citizens from natural radiations and compares it to estimates from other man-made sources.

Table 5-A Average Doses From Radiation in the United States in 1970

Source	Average Dose, mrem/year*		
Environmental			
Natural			
Cosmic Rays	44		
Terrestrial Radiation			
External	40		
Internal	18		
Total	102 →	102	
Global Fallout		4	
Nuclear Power		0.003	
Total		106 →	106
Medical			
Diagnostic		72	
Radiopharmaceuticals		1	
Total		73 →	73
Miscellaneous			3
Grand Total			182

*Field measurements are usually made in units of μR/hr. For X- and gamma radiation 1 μR/hr = 1 mrem/hr = 8.8 mrem/yr.

The total annual dose to an average United States citizen is about 182 mrem/yr. The largest fraction (58%) is contributed by environmental sources. Of the environmental sources, cosmic radiations contribute the most. Cosmic radiation from outer space is primarily absorbed in the upper atmosphere, however, secondary radiations are present at ground level. Altitude is the single most important cause of variation with Florida (near sea level) having a lower than average rate, about 30 mrem/yr while the higher elevations of Colorado exceed 100 mrem/yr. (NCRP 1975).

The fraction of the environmental radiation dose of interest here is the external terrestrial radiation and to a limited degree, internal terrestrial radiation. These two catagories can be enhanced by the technological activities of man, such as the mining and processing of ores. Other activities such as dredging, road building and sanitary land fill operations have potential for enhancing local background radiation. It should be noted, for reference, that the largest man-made radiation dose contributor is that of diagnostic uses of x-rays, largely unregulated. The current value of 72 mrem/yr has been increasing through the years with little indication that it will not increase in the future.

5.1 Background Levels

In the continental United States, the external terrestrial radiation arises primarily from gamma ray emissions of the thorium series, the uranium series and potassium-40. The latter is a naturally occurring isotope of potassium with a geologic age half-life. In typical circumstances, the thorium series and the potassium-40 combine to account for over 70 percent of the external exposure. However, in Florida the contribution to the external terrestrial radiation component by the

the uranium series probably accounts for a higher percentage of the external terrestrial radiation and all of the man-enhanced increases.

The overall average level in Florida is lower than the national average given in Table 5-A. Literature values show a considerable range for Florida, probably due to inclusion of different land types including disturbed lands: Golden (1968) - .26 mR/yr (3 μR/hr); Levin, et al. (1968) - 17 mR/yr (1.9 μR/hr); State of Florida (DHRS 1977); - 16 mR/yr (1.8 μR/hr); and Oakley (1975); 12 mR/yr (1.4 μR/hr). The total average external background radiation level (cosmic + terrestrial) in Florida is expected to be between 6.3 and 4.7 μR/hr (41 to 55 mrem/yr).

5.2 Gamma Radiation On-Site

A radiological survey of the terrestrial gamma levels on the site is reported in Section 38.G of the Duette DRI. The average total external gamma level for the entire property (over 200 measurements) is approximately 5.1 μR/hr, which can be converted to an annual exposure of 45 mrem. This compares to the national average of 84 mR/yr. (44 mR/yr. cosmic and 40 mR/yr external terrestrial). The site is lower than the U.S. average for the following possible reasons:

1) The lower elevation reduces cosmic by atmospheric shielding

2) The limited thorium content of soils restricts the contribution from that decay series

3) The lower than normal potassium concentrations in the soils reduce the contribution from K-40, and higher than average water tables add to the shielding of the subsurface uranium series and lowers the diffusion transport of radon-222 to the surface.

The potential for background enhancement by mining in Florida is shown dramatically in Table 5.2-A. Debris lands are over four times background, but, of course, debris lands have not been produced since the 1940's.

Table 5.2-A Gamma Radiation Levels of Various Land Types in Florida

County & Land Type	No. of Sites	Gamma Level, μR/hr Geom. Mean	Range
Polk Co.			
Unaltered	9	5	4-7
Unmined Radioactive Fill	1	9	-
Sand Tailings	11	11	6-16
All Overburden Reclaimed	16	13	7-33
Capped and mixed clays	6	17	11-24
Debris	8	22	11-54
Alachua Co.			
Unaltered	6	6	5-8

after Roessler, et.al. 1978

The other three categories; sand tailings, overburden reclaimed, and clay fraction associated reclamations, increase the background by 100 to 200 percent. Note that the range in each category is large and the final level depends upon many interrelated factors. Specific reclamation techniques for the Duette site will be discussed and the impact addressed.

The higher levels (>6 μR/hr) found on the proposed site are interesting. The highest reading (48.1 μR/hr) observed was in the centerline of State Road 37. This reading dramatically emphasizes the degree to which man (usually unknowingly) changes the radiation distribution in the environment. The next highest reading observed was 24.6 μR/hr near the creek bed of the Manatee River East Fork. From a normal reading over high ground the radiation level rose rapidly as the elevation dropped approaching the creek bed. The influence of lower elevations can be seen in other readings near the creek beds. The increased radiation levels are thought to be due either to outcrops of radioactivity bearing strata, the decreased shielding of the high activity strata by overburden, or both conditions. In whichever case, the levels dramatize the large variability of the natural radiation environment.

6. AIRBORNE RADIOACTIVITY

Airborne radioactivity over unaltered lands arises from two major sources. Particulates containing the naturally occurring radioactive materials such as the uranium series become airborne as "dust". The second source is the diffusion of the gas radon-222 out of the soil surface from a subsurface source and the subsequent decay progeny produced in the atmosphere. Radioactivity in particulates are normally measured as gross alpha and gross beta activities per cubic meter of air sampled at a one meter height with a membrane filter. Radon-222 is measured directly by sampling of the air with a evacuated scintillation cell. Radon progeny are evaluated in terms of the Working Level unit (WL). The potential contribution of radon-222 to atmospheric radioactivity can be correlated to measurements of the surface flux of radon in units of pCi/m^2 s. All levels and measures of airborne radioactivity are strongly dependent upon local meteorology.

6.1 Airborne Particulates

Gross beta measurements have made at numerous locations in Florida and across the nation in connection with off-site monitoring of nuclear power stations and other nuclear facilities, as well as the Environmental Radiation Ambient Monitoring System of the EPA. In general, ambient levels of gross beta range between 0.1 and 1.0 pCi/m^3 if the site is unaffected by recent fallout or dusty conditions. Gross alpha measurements are much less frequent in the literature and average one to two orders of magnitude less than the beta measurements.

One of the most specific baseline studies of airborne particulate radioactivity in central Florida was conducted by the EPA in conjunction with the Central Florida Phosphate Areawide EIS (Partridge et.al. 1977). A summary of the ambient air sampling network for nonphosphate areas of

Polk County is shown in Table 6.1-A. The data clearly show that the U-238 series is the more important and that the decay series is in equilibrium. Any gross alpha measurement will be at least four times the concentration of one of the U-238 series measurements or > 0.0012 pCi/m^3. The concentrations of the U-235 series are expected from the percent abundance of that series. The concentration of Th-232, in relationship to U-238, validates the earlier discussion on the limited importance of thorium series in central Florida. The Th-232 and Th-228 appear not to be in equilibrium, however, one unusually high reading in the network for Th-228 contributed over 50% of the mean value.

The mining operations have potential for increasing airborne radioactivity from windborne dust during land clearing, dragline activities and post-mining operations. The benefication process ends with drying to remove moisture. The predominate airborne emissions from the phosphate industry are fine dust from these dryers. Control devices include the use of dry or wet scrubbers. The impact of these emissions must be addressed.

6.2 Radon-222 and Radon Flux

Radon-222 is a natural constituent of all air, but its concentration may vary over a wide range depending on the radium content of the upper layers of the earth and the prevailing meteorological conditions. Table 6.2-A presents information about the radon-222 content of ambient air at several locations in Florida (Williams et.al. 1965). Morning values are higher because of the limited atmospheric mixing in the early hours of the day.

Radon-222 is rather non-radiotoxic, since it is a noble gas. However, its progeny are of serious concern. If the progeny were in equilibrium

Table 6.1-A Ambient Air Particulate

Radionuclide Concentrations in Polk County

Decay Series	Radionuclide	Concentration, pCi/m^3 Mean[a]	Std. Dev.
Uranium-238			
	U-238	0.00039	0.00034
	U-234	0.00039	0.00034
	Th-230	0.00042	0.00011
	Ra-226	0.00048	0.00045
Uranium-235			
	U-235	0.00003	0.00002
	Th-227	0.00005	0.00002
Thorium-232			
	Th-232	0.00004	0.00001
	Th-228	0.00015	0.00004

a) Six stations with two samples at each of approximately 5000 m^3

Table 6.2-A Radon-222

Content of Ambient Air in Florida

	Radon-222, pCi/l	
Location	Morning	Afternoon
Bartow	0.276 (171)*	0.042 (157)
Orlando	0.083 (317)	0.019 (266)
Jacksonville	0.052 (180)	0.028 (172)

* ( ) indicates number of samples

with 100. pCi/l of radon-222, then the air would be at 1.0 WL.

Working Levels are of particular concern in enclosed spaces such as homes built on reclaimed lands. Because of the wide variation in hourly measurements of radon-222 in air due to atmospheric conditions, radon-222 flux measurements from the soil surface have been determined to be a valuable indicator of environmental impact. Table 6.2-B indicates expected radon flux baseline levels (unaltered lands) and elevated levels over various types of phosphate related lands. It is apparent that mining and its waste products have increased the radon flux from the reclaimed lands. The potential elevation of radon fluxes for the Duette site will be estimated and the impact evaluated.

Table 6.2-B Summary of Radon-222 Flux Characteristics of Various Land Types in Polk County (Roessler et al 1978)

Land Types	No. of Sites	Radon-222 Flux, pCi/m^2 s	
		Mean	Range
Unaltered	17	0.2	<0.1-1.7
Unminded Radio-active Fill	2	1.3	0.6-2.8
Tailings	19	0.7	<0.1-2.7
All Overburden	27	1.5	<0.1-12.8
Capped and Mixed Clays	6	1.6	0.3-7.2
Uncapped clays	2	4.4	3.6-5.4
Debris	15	4.2	1.7-13.7

7. WATER QUALITY

Two water regimes will be considered with respect to radiological water quality; surface waters and groundwaters. The site contains three surface water drainage basins. Of particular importance is the fact that the site comprises about 12 percent of the Lake Manatee watershed. The groundwater system can be divided into two major sub-divisions: shallow aquifers above the Hawthorn and the Floridan aquifer beneath the Hawthorn.

7.1 Surface Water Radioactivity

Radium-226 in surface waters of the USA is generally low (between 0.03 and 1.0 pCi/l) except for certain locations such as mineral springs, waters with high solids content, and waters that drain fertilized farming areas. This distribution can be seen in Table 7.1-A. The latter nine entries are specific to Florida.

It is important to point out that the method of sample preparation and handling for radium-226 analysis can change the result by an order of magnitude. Dissolved, undissolved or total radium may be fractionated by various filtering procedures and reported differently. Acid treatment techniques may change radium from an undissolved state to a dissolved form. Thus, comparison of sites evaluated by different authors is most difficult. Order of magnitude changes below 1 pCi/l should not be considered significant without additional knowledge of exact procedures.

Table 7.1-B contains a summary of surface water radium-226 concentrations for the site and two downstream stations. The dissolved radium values were less than 0.8 pCi/l for four out of six of the on-site samples. The two positive samples

Table 7.1-A Radium-226 in Surface Waters in the U.S.A. and Florida

Type	Location	Radium-226 pCi/l	Ref.
River Waters	Average North America	0.03	Lo 56
Mississippi River	St. Louis, Mo.	1.2-2.9	Lo 56
Great Salt Lake	Utah	5	Lo 56
Curie Spring	Boulder, Colorado	267,000	Lo 56
Ohio River	Pennsylvania	0.6	Lo 56
Surface Water Supply	Chicago, Il.	0.03	Ho 63
Lithia Springs	Lithia, Fl.	0.68	Ir 76
Alafia River	Lithia, Fl.	0.06	Ir 76
Peace River	Ft. Meade, Fl.	0.12	Ir 76
Proposed Four Corners Mine Site	Hillsborough and Manatee Co., Fl.	0.18	Mo 77
Osceloa Nat. Fr.	Columbia Co., Fl.	0.07	Mi 77
Peace River Basin	Hillsbrgh, Polk, Manatee and Hardee Cos., Fl.	0.94	Ir 76
Lake Manatee	Discharge at Sullivans Bridge	0.32	Jo 75
Manatee and Myakka Rivers	(S12, 525, T34S, R21E) (S15, T35S, R22E)	0.1	Bo 76
Hookers Prairie	Bradly Junction, Fl.	0.8	Ge 78

Table 7.1-B Summary of Surface Water Radium-226 Concentration On Site and Off Site.

Date Collected	Description	Radium-226, pCi/l	
		Undissolved	Dissolved
8/30/76 (A-3)	East Fork, Manatee River Entrance, S9T34R22	<0.8	<0.8
8/30/76 (B-3)	East Fork, Manatee River Exit S18T34R22	<0.8	1.8 ± 1.1
8/30/76 (D-3)	North Park, Manatee River S20T33R22	<0.8	<0.8
8/30/76 (E-3)	Creek Crossing Rt. 39 West Side, S13T33R21	1.1 ± 1.1	<0.8
8/30/76 (F-3)	Small Stream, Middle of Track S18T33R22	<0.8	<0.8
8/30/76 (G-3)	North Fork, Manatee River Exit S7T34R22	0.8 ± 0.8	2.4 ± 1.0
8/28/76 (N-3)	Manatee River at Lake Manatee	<0.8	<0.8
8/27/76 (O-3)	Manatee River at Bridge, S.R. 64	<0.8	<0.8
8/27/76 (P-3)	Unreclaimed Lake – 3' sample, 6' deep	<0.8	<0.8
8/26/76 (Q-3)	Unreclaimed Lake Surface Sample	<0.8	<0.8
8/27/76 (Q-3)	Unreclaimed Lake – 12' deep	<0.8	3.0 ± 1.1
( ) (R-3)	Old Colony Mine Pit, Surface Sample	<0.8	1.2 ± 1.1

Table 7.1-8 Continued.

Date Collected	Description	Radium-226, pCi/1	
		Undissolved	Dissolved
8/27/76 (R-3)	Old Colony Mine Pit, 12' Sample	< 0.8	< 0.8
8/30/76 (R-3)	Old Colony Mine Pit, 24' Sample	1.6 ± 1.2	1.2 ± 1.2
8/30/76 (S-3)	Settling Area, Agrico	< 0.8	< 0.8

were 2.4 ± 1.0 and 1.8 ± 1.1 pCi/l. Samples from the Manatee River at State Road 6 and at Lake Manatee were both less than 0.8 pCi/l of radium-226.

Potential contamination of off-site surface waters must be addressed. The water management program, presented in the Duette DRI, will determine radiological contamination during the mining phase, whereas the reclamation plan with its on-site drainage system and preventative measures against turbid runoff will determine the long term impact. It is important to recognize that radium is highly insoluble in comparison to other water quality parameters and measures to control other non-radioactive contaminates is normally sufficient to limit the impact of radium-226.

Although the thorium content of the soil, overburden, and matrix in central Florida is much lower than the national average, concern has been expressed for the potential contamination of waters by radium-228. In order to provide a baseline for this radionuclide and, in addition, for uranium, five surface water samples from the site were submitted for radium-228 and uranium-238 analysis. The data are summarized in Table 7.1-C. The radium-228 concentrations expected from comparison to U/Th ratios in central Florida are less than 0.01 pCi/l. Osmond et.al. (1971) analyzed approximately 60 samples of natural Florida waters. The majority were well waters and springs but one river, one creek and two lakes were included and these four samples averaged 0.00009 ppm U with a maximum value of 0.00019 ppm. The analytical technique was extremely sensitive.

Table 7.1-C Uranium-238 and Radium-228 Concentrations in Surface Waters from the Duette Site

Location	Date Sampled	Concentration, pCi/l Uranium-238	Radium-228
A	8/31/78	ND	<BLK
B	8/31/78	ND	<BLK
D	8/31/78	ND	ND
E	8/31/78	ND	<BLK
G	8/31/78	ND	<LLD

NOTES:

See Figure 15.B(2) Duette DRI for site locations

ND denotes not detected or no net count in sample

Limit of detection for uranium-238 was 0.04 pCi/l

<BLK denotes possible net count but smaller than distilled water blank

<LLD denotes possible count but smaller than the lower limit of detection of 0.9 pCi/l for radium-228

7.2 Groundwater Radioactivity

The potential of groundwater contamination with radium-226 or other contaminants due to phosphate mining operations has been a major concern. A review of the literature and analysis of radium-226 in groundwaters of west central Florida is presented by Kaufmann and Bliss (1977). They statistically analyzed available radium data from 1966 and from 1973-1976 in three strata: upper water table, Upper Floridan aquifer, and Lower Floridan aquifer. Each water resource was considered in three geographic areas of west central Florida: mined (mineralized) areas, unmined mineralized areas, and non-mineralized areas. The basic data summary is shown in Table 7.2-A. All data for a particular set was found to be distributed log normally. Therefore, geometric means are considered for comparison of sets.

The mined area appears to have a higher radium-226 in the water table aquifer, but statistical tests indicate no significant difference between the 0.17 and 0.55 pCi/l. No data were summarized for the non-mineralized area.

When the Upper and Lower Floridan aquifer data were considered, mined areas and nonmined areas were all approximately equal and both portions of the aquifer were similar. Statistical tests on the comparison of non-mineralized data versus the mining areas showed that the Floridan had higher concentrations of radium-226 in the non-mineralized areas. The Floridan aquifer showed significantly higher levels than the water table aquifer.

Table 7.2-A Summary of Radium-226 Data in Central Florida Aquifers

Area Description	Water Table		Aquifer: Upper Floridan		Aquifer: Lower Floridan	
	No.	pCi/l*	No.	pCi/l	No.	pCi/l
Unmined Mineralized	23	0.17	5	2.30	24	2.0
Mined Mineralized	12	0.55	10	1.61	6	1.96
Nonmineralized (Control)	NO DATA		3	5.1	14	1.4

Source: After Kaufmann and Bliss, 1977

* All data are geometric means of author's preferred data.

Note: Drinking water standard for total radium is 5 pCi/l

Kaufmann and Bliss did not consider gamma logs of deep wells. As discussed previously, gamma logs to 1,000 feet show considerable radioactivity in the Hawthorn formation overlaying the Floridan aquifer. The gamma logs strongly suggest that the Lower Hawthorn may itself a source of radium-226 in the Floridan aquifer.

Gamma logs of the non-mineralized areas may explain the observation that the radium in the Floridan aquifer in non-mineralized areas was either equal to or higher than both mined and nonmined mineralized areas (Kaufmann and Bliss, 1977). Uranium, and therefore radium are associated with the entire Hawthorn.

Another finding by Kaufmann and Bliss (1977) was the presence of three separate populations of radium-226 in the Lower Floridan aquifer. These groups had geometric means of 0.7, 3 and 10 pCi/l, respectively. They state that: "elevated levels of radium-226 in the Lower Floridan aquifer can be due to a number of natural factors unrelated to phosphate mineralization or waste management in the phosphate industry". They mention increased solubility of radium in groundwater enriched by chloride and the salt water intrusion due to the pumping from the Lower Florida aquifer.

The Duette DRI Section 38.(2) supports this theory. Packer testing of a 2,000 foot well yielded 0.8 pCi/l at one increment of depth, higher activity over larger increments (1.7 to 2.6 pCi/l) and 12.7 pCi/l at one small increment. The radium and water quality were directly related: the depth increment pumping the 12.7 pCi/l radium-226 concentration had over 50,000 ppm Na^+, the lowest radium (0.8 pCi/l) was associated with water having 18 ppm Na^+.

Kaufmann and Bliss found radium-226 in wells of Sarasota County to be two orders of magnitude greater in the water table aquifer and almost one order of magnitude greater in the Floridan aquifer. Dissolution of radium-226 from the Upper Hawthorn formation may account for the first finding. Interaction with salt water intrusion may account for the second finding.

Morton (1977) has plotted dissolved radium-226 versus depth for three central Florida groundwater surveys. The graph (Figure 7.2-1) has a distribution that is very similar to the gamma well log in Figure 4.2-2, except for the two high concentrations at the 700-800 foot increment and the 1200-1300 foot increment. The two could be associated with high salinity levels in the aquifer sampled.

Table 7.2-B summarizes additional data on radium-226 in groundwater taken in recent years for various environmental assessments of proposed phosphate mines including the Duette DRI. Overall, the radium concentrations follow the same pattern with depth as those in Figure 7.2-1 and the deep gamma logs. Note that the Hawthorn samples (Four Corners Mine and Duette Mine) show relatively high concentrations compared to the rest of the measurements.

The potential for the contamination of groundwater by the activities of the mining or by the final condition of the land when returned to other uses must be addressed. However, because radium-226, the most serious radioactive contaminant, is found in all subsurface strata at various concentrations including some that are much higher than the mined matrix, the identification of additional contamination beyond natural causes and the determination of its source is

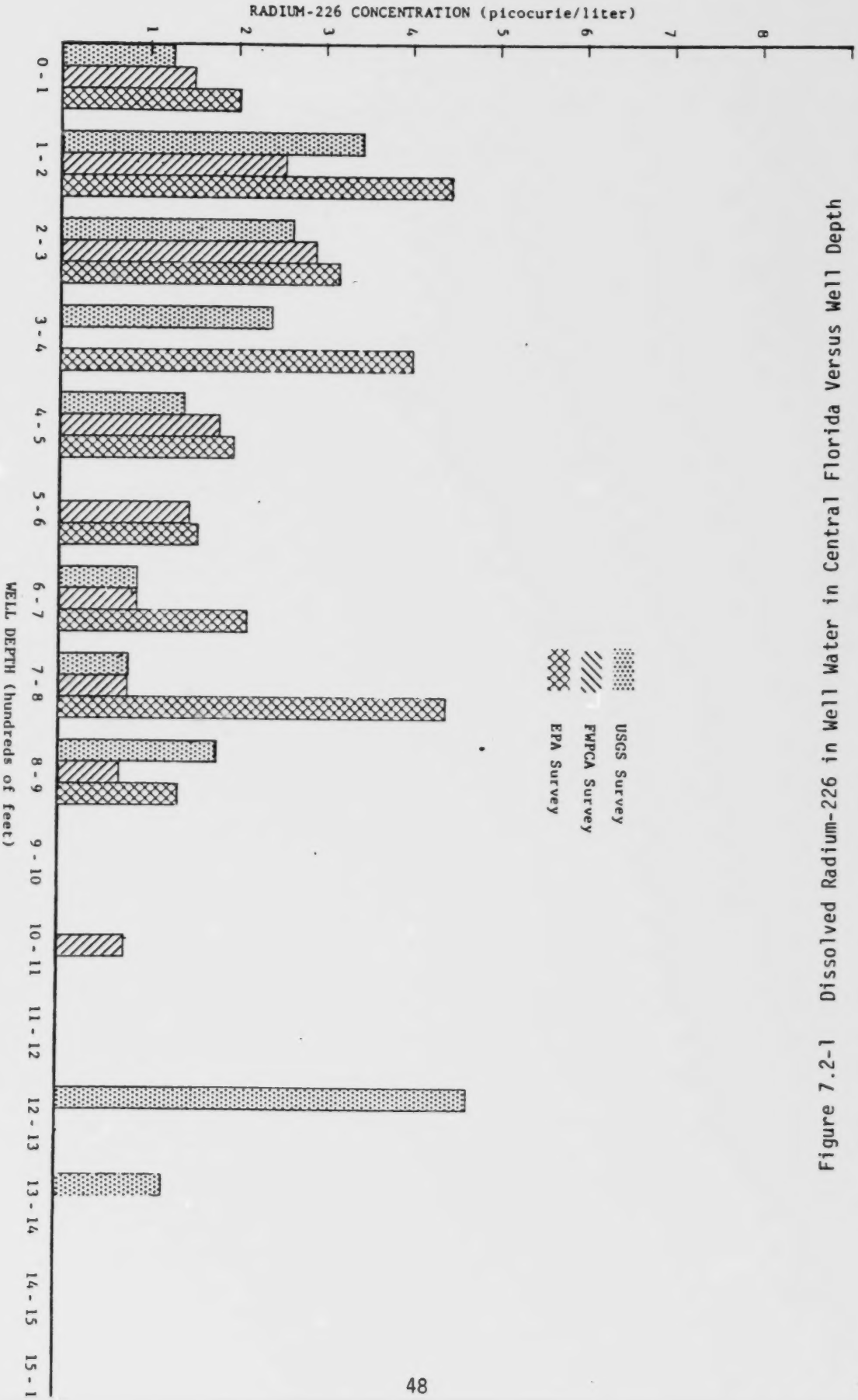


Figure 7.2-1 Dissolved Radium-226 in Well Water in Central Florida Versus Well Depth

Table 7.2-B Additional Radium-226 Concentrations in Central Florida Groundwater

REF.	YEAR	LOCATION	AQUIFER	No. of Samples	Ra-226, pCi/l Mean
Mo 77	1977	Four Corners Mine	Shallow	31	1.5
Mo 77	1977	Four Corners Mine	Hawthorn	4	2.8
Mo 77	1977	Four Corners Mine	Upper Floridan	2	1.6
Mo 77	1977	Four Corners Mine	Avon Park	2	1.8
Ge 78	1976/78	Hookers Prairie	Shallow	16	1.1
Ge 78	1976	Hookers Prairie	Secondary	1	0.5
Ge 78	1976/78	Hookers Prairie	Floridan	2	3.4
Appendix C Duette DRI	1975	Duette Mine	Shallow	3	<2.4
Appendix C Duette DRI	1975	Duette Mine	Hawthorn	1	5.5
Appendix C Duette DRI	1975	Duette Mine	Upper Floridan	6	2.1
Appendix C Duette DRI	1975	Duette Mine	Lower Floridan	7	3.3

of an exceedingly complex problem.

8.[illegible] SUMMARY

Baseline conditions at the proposed site are as follows:

Subsurface Radioactivity - Uranium and radium-226 measurements confirm high activities either just above or in top of matrix. Overburden has concentrations of radioactivity typical of west central Florida, however, the Duette matrix is deeper than in most current mines. Uranium and radium-226 continues throughout the matrix and into the Hawthorn and exceed the matrix concentrations.

Gamma logs show high levels at the top of the matrix, some continued higher radioactivity through the Hawthorn with a decrease within the Floridan aquifer.

The U/Th ratio in subsurface strata is much greater than the national average. Thus, radium-228 is not considered a potential contaminant.

Matrix Radioactivity - Radium-226 is approximately 5 to 8 pCi/g or less than one-third of that observed at currently operated mines in west central Florida.

Gamma Radiation - The external gamma radiation is approximately 5.1 μR/hr over unaltered lands on the site. Typical Florida background radiation ranges from 4.7 to 6.3 μR/hr.

Airborne Radioactivity - The agricultural nature of land indicates low airborne particulate activity: less than 1 pCi/m^3 gross beta, less than 0.01 pCi/m^3 gross beta, and less than 0.001 pCi/g for specific long lived radionuclides such as U-238, Th-230, Ra-226, etc.

Ambient levels of radon-222 are expected to be less than 0.1 pCi/l.

The surface flux of radon-222 on the unaltered site is expected to not exceed 1 pCi/m^2s.

Surface Water Radioactivity - Radium-226 levels are between less than 0.8 to 2.4 and normally less than 1 pCi/l. These values are higher than the national average, but comparable to other surface water in unmined areas of Florida; Uranium and Ra-228 concentrations in surface waters are below normal detection limits.

Groundwater - Radium-226 levels are between less than 0.8 and 6 and normally less than 3 pCi/l in important aquifers. Concentration appears to be related to depth and, therefore, to radium in the immediate media. Poor water quality, especially Na^+ (or Cl^-) may enhance radium content.

PART II

RADIOLOGICAL ENVIRONMENT IMPACT

PART II

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PART II RADIOLOGICAL ENVIRONMENT IMPACT

1. INTRODUCTION

The baseline conditions of the radiological environment of the site have been summarized in Part I. The proposed Duette mine may alter these baseline conditions. The purposes of this section will be: (1) to describe the redistribution of the radioactivity and radiation due to the activities of the proposed mining, (2) to propose potential contamination and exposure pathways for the radioactive pollutants, (3) to predict or estimate from the best data available the effects on man or the environment, (4) to provide a comparative measure for each end-point against which the effect can be placed in its proper perspective, and (5) to substantiate the basis for mitigative measures whenever such procedures are deemed necessary.

2. RADIOACTIVITY IN MEDIA

The following discussion will attempt to follow the flow of radioactivity through the mining, beneficiation, and drying of the fertilizer product. Data are based both upon measured activities in the overburden and matrix at the Duette site and are compared to the more intensively investigated impacts in the west central Florida mining district. Actual concentrations will not be known until the plant is operational, however, this discussion will attempt to use conservative data (i.e., those that may overestimate adverse effects).

2.1 Mining and Beneficiation

In the mining process, the overlying topsoil, sands, strata, and leached zone (if present) must first be stripped away to gain access to the phosphate matrix. These overlying materials are collectively known

as overburden and may be piled into the previous mine cut resulting in a series of spoil banks. Core analyses have shown the radium-226 profile in the site overburden to range from less than 1 pCi/g near the surface to a high of about 18 pCi/g at the matrix interface. A dragline cannot precisely divide the strata and thus overburden may include some inadvertent matrix. The problems posed by this radioactivity bearing material in reclamation will be discussed in a later section.

The matrix must be removed and slurried to a washer/beneficiation plant. The complete process and distribution of radioactivity for current practice (Roessler et.al., 1978) and for the Duette site (Duette DRI Table C-5(1)) is shown in Figure 2.1-1. In general, the first step produces a course product known as pebble, an intermediate sized product known as flotation feed, and a fine clay product. The latter may be about 30 percent of the incoming weight and has no use. These clays are in a liquid slurry (about 3 percent solids) and the liquid must be recovered for reuse. Thus, the clays are routed to a settling area. There, the fine particles settle and the supernatant is decanted for recycle. The clays in west central Florida have as high a concentration of radium-226 as the input matrix (both on a dry weight basis) and the level depends upon the efficiency of the washer plant. The west central Florida clays average about 45 pCi/g for radium-226. By pilot plant studies with the matrix, the clays at the proposed site range from 3.2 to 5.6 pCi/g radium-226. All clays from the pilot plant had less radioactivity than the input matrix, indicating either an excellant separation effeciency or a different type of clay.

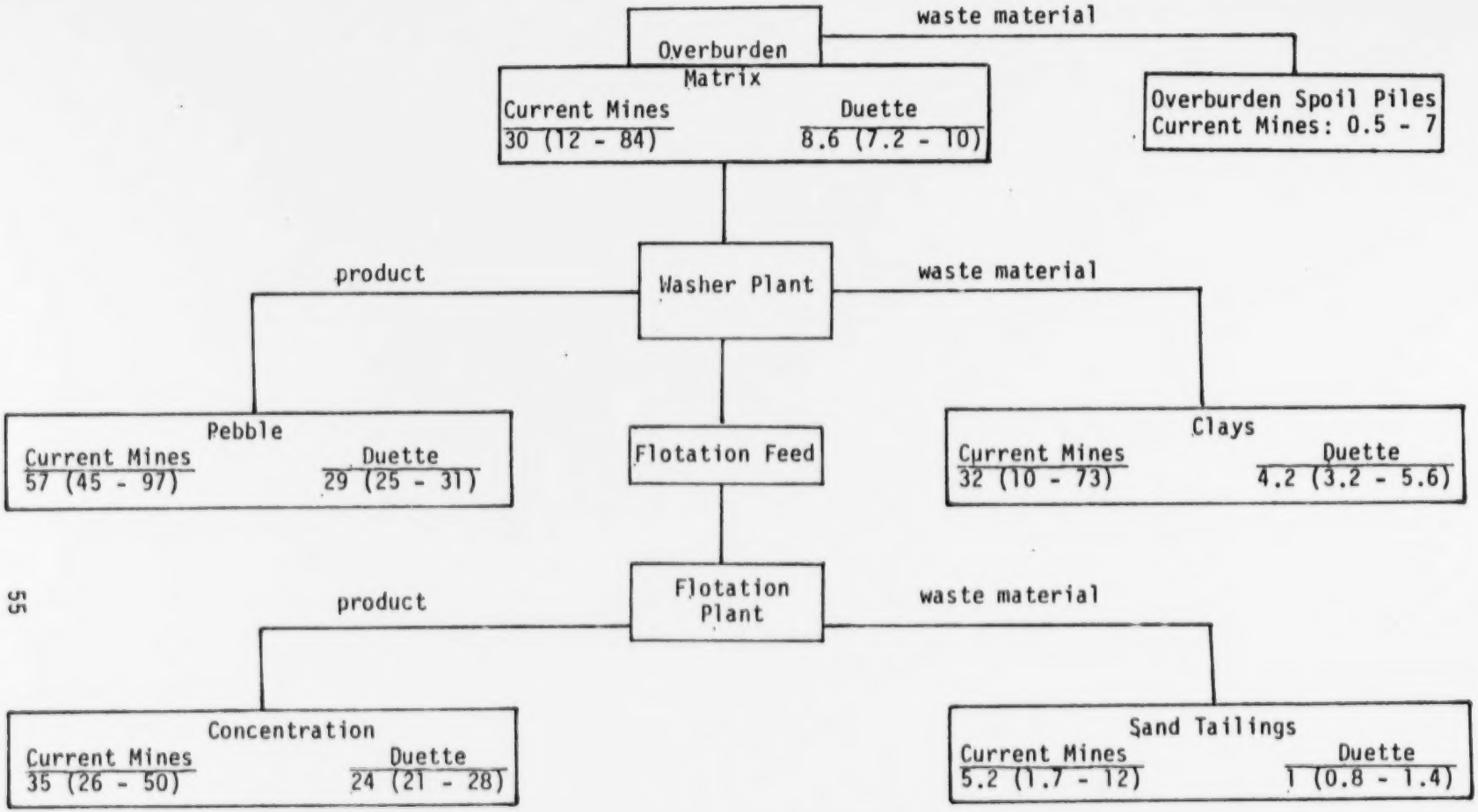

Figure 2.1-1 Comparison of Radium in Current Central Florida Products and Wastes to Expected Values for the Duette Site. (Ra-226 in pCi/g)

The coarse fraction from the washer plant, pebble has a concentration of radium in excess of that in the matrix. The pilot plant separation of the site matrix yielded a range of from 25 to 31 pCi/g radium-226 for pebble. This is approximately one-half of the average found currently in the west central Florida plants.

The second physical processing step is flotation and the two fractions produced are the concentrate and a sandy waste fraction usually termed tailings. The tailings normally represent about 40 percent by weight of the incoming matrix and should contain little phosphate (about 10 percent) and a small fraction of the radioactivity. The west central Florida tailings now average about 5 pCi/g. Samples from the pilot plant indicate Duette tailings having a radium-226 concentration of 1 pCi/g. This value also appears to represent a very efficient separation.

For design purposes, it is expected that full scale operations will result in sand tailings and a waste clay fraction having somewhat higher radium-226 contents due to efficiency differences. However, concentrations double the pilot plant should represent an upper limit.

In summary, the three primary materials available for land reclamation at the Duette site are overburden with a radium-226 concentration ranging from 0.5 up to about 16 pCi/g, a sandy tailings fraction with a concentration of about 1 to 2 pCi/g radium-226, and the clay fraction with a radium-226 level of approximately 4 to 8 pCi/g. The products to be subsequently handled, as in the drying operation, will have a radium-226 concentration of about 24 to 29 pCi/g. There are limited indications that the beneficiation process may slightly enrich the products in radium-226 over uranium (Roessler, 77u). However,

for the purpose of any impact assessment, it will be assumed that the ore processing will not change the uranium to radium equilibrium.

Many of the impacts of mining and beneficiation are indirect and will be discussed under the subsequent appropriate subsection. A potential direct impact is that of occupational exposures at either the dragline area or beneficiation plant. Prince (1977) surveyed six plants and found that the external gamma radiation levels around the dragline to be near baseline (average 5 μR/hr, range 4-7 μR/hr). The beneficiation plant, gamma radiation levels were about twice background, however, a work-station survey found occupancy factors were low enough to reduce the annual exposure to insignificant levels. Radon progeny as measured by Working Levels were also low: 0.0004 WL (average of seven plants) in dragline areas and 0.0007 WL (average of four plants) near beneficiation processes. For comparative purposes, slab-on-grade structures of the general public over unaltered lands in Polk and Alachua counties range from 0.001 to 0.032 WL with a mean of 0.005 WL (geometric mean 0.004 WL). Direct radiological impacts to operating personal at mining and beneficiation processes are therefore minimal.

2.2 Drying, Storage and Shipping

General descriptions of the wet rock storage, dryers, dry rock storage and product loading for off-site shipment are presented in a discussion of the proposed activity. The major impact of this phase will likely be the radiation dose from inhalation of airborne particulates. This impact will be discussed under Section 4. that follows.

Other potential impacts involve consideration of the occupational exposures at these operations. Potential hazards to be considered are gamma radiation doses, exposure to radon progeny, and inhalation of long-lived radionuclides. Exposure pathways include:

1) storage areas: exposure may occur on catwalks, over bins, at the bottom of bins and near other piles.

2) loading tunnels: exposure may occur inside of the tunnel either before or during operation. Non-ventilated tunnel represent a special area of concern.

3) dryer building: exposure may occur inside control rooms or outside on catwalks or at bottom of cyclones.

4) rock loading: exposure may occur from storage bins, on catwalks, and especially during train car loading.

Prince (1977) has studied the occupational radiation exposures in the industry. Of the exposure pathways mentioned above, wet rock storage piles yielded the highest potential gamma radiation level with an average rate at ten plants surveyed of 67 μR/hr. However, occupancy time at these locations is extremely small making the annual exposure to an individual insignificant. In areas when the occupancy factor is high, the elevation in gamma radiation was low. For example, dryer central rooms in four plants averaged only 8 μR/hr.

Prince's results for airborne radon progeny hazards indicated the storage and transfer tunnels, under wet rock piles, to be the most serious hazard. Working Level measurements at eleven sites yielded levels between 0.0007 WL to 0.960 WL. The current standard for uranium miners converts to 170 hours per month at 0.33 WL. An occupational time-place study indicated a low occupancy factor for tunnels, however, the levels were sufficiently high for Prince to recomend mechanical ventilation for all tunnels and limited access by personnel. The Duette operation, having both a lower radioactivity concentration in the stored material and properly ventilated

tunnels, should not experience adverse occupational exposures. Gross alpha measurements in airborne particulate have not indicated a serious hazard from the long-lived radionuclides. Dose calculations from airborne emissions will be discussed in Section 4.

2.3 Overburden and Reclamation

The existing profiles of radioactivity with depth shown in Figure 4.1-3 and 4.2-2 will be altered by the mining and subsequent reclamation. The new distributions of radioactivity will be determined by the concentrations in the mixed overburden and various waste products and by the methods of reclamation.

The radium-226 (and uranium-238) concentration in the post-mining overburden can be estimated to be 1.5 pCi/g by the weighted averages of materials given in Table 4.1-A. Any stored topsoil to be replaced should have a lower radioactivity ($\sim$0.5 pCi/g).

The two waste products, sand and clay, to be used in reclamation will have expected concentrations of radium-226 of 1 pCi/g and 4.2 pCi/g respectively. Mixtures of sand and clay can be estimated by a weighted average:

$$r_{mix} = (f_{sand} \cdot r_{sand} + f_{clay} \cdot r_{clay})/(f_{sand} + f_{clay})$$

Where r = radium-226 concentration

f = weight fraction of sand or clay

For the proposed 2.5/1 ratio of sand to clay, the final concentration of radium-226 is predicted to be 1.9 pCi/1.

The reclamation plan calls for 80% of the reclamation to be with this sand clay mixture. Another 13% will be by covering sand tailings with two feet of overburden. The remaining 7% of the reclaimed land will be

the final clay setting area.

Figure 2.3-1 illustrates the expected radioactivity profiles under various reclamation catagories. Overburden lands will have an average radium-226 level of 1.5 pCi/g, but with several "spikes" throughout the profile of inadvertent matrix or high activity material originally just above the matrix. When a sand and clay mix is used, the average radium-226 increases to 1.9 pCi/g and several higher activity "spikes" may exist due to clay lenses. The tailings reclaimed land should be uniform with radium-226 about 1.0 pCi/g throughout. Finally, the clay sediments are expected to yield an average concentration of 4.2 pCi/g with both higher and lower spikes. A small amount of low activity overburden (~0.5 pCi/g) or topsoil is shown in each profile.

3. ALTERATION OF TERRESTRIAL GAMMA RADIATION

The redistributed radioactivity in reclaimed lands will alter the terrestrial gamma radiation. Table 5.2-A illustrated the elevation of gamma radiation that has occurred over various land types as a result of mining in Polk County. Because of the lower radioactivity at the Duette site the land should not experience this degree of elevation.

The predicted impact has been estimated by consideration of the expected uranium, thorium, and potassium contents of various post reclamation land types. Beck and de Planque (1968) have given exposure rates in air for each ppm of uranium, thorium and potassium in soils. From these data Table 3-A was constructed. Note that in order to be conservative, no credit was taken for the low activity topsoil or its shielding properties.

The reclaimed clay settling area presents the highest apparent impact. However, it represents a small fraction (7 %) of the site and its high

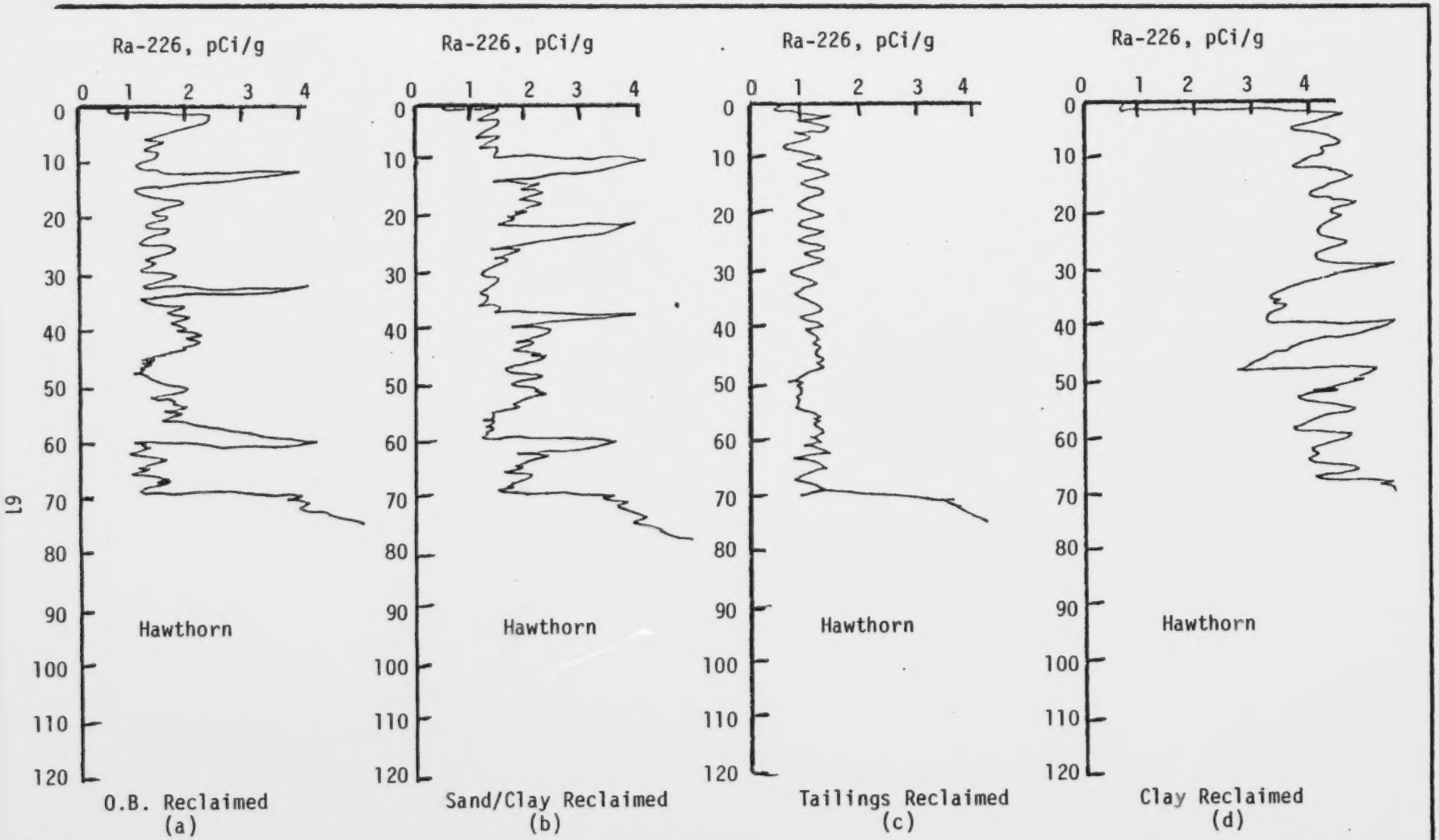

FIGURE 2.3-1

PREDICTED RADIOACTIVITY PROFILES

Source: W. E. Bolch, Ph.D.

U.S. EPA - REGION IV
DRAFT ENVIRONMENTAL IMPACT STATEMENT FOR SWIFT AGRICULTURAL CHEMICALS CORPORATION PROPOSED DUETTE MINE
MANATEE COUNTY, FLORIDA

water content may reduce the gamma level by shielding. Reclaimed clay areas are not particulary sited for residential development and the rest of the reclaimed lands are expected to meet the <10 μR/hr interim recommendation for gamma exposure levels at new structure sites on Florida phosphate lands (EPA,76).

Table 3-A Gamma Radiation Characteristics of Reclaimed Land On The Duette Site

Land Type	Predicted Gamma, μR/hr @ 1 m	Cosmic Contribution, μR/hr	Total μR/hr
Overburden Reclaimed	3.5	3.6	7.1
Sand/Clay Mixture	5.1	3.6	8.7
Tailings Reclaimed	2.3	3.6	5.9
Clay Reclaimed	11.2	3.6	14.8
Weighted Average for the site	5.2	3.6	8.8

4. AIRBORNE RADIOACTIVITY

There are two major sources of airborne radioactivity that need to be addressed. During the mining and ore processing phase, airborne particulates and their associated radioactivity is the more important aspect. Fugitive dust control has been adequately addressed in other sections. The impact of the dryer, storage, and loadout emissions, however, requires further consideration. Offsite transport of the radioactivity and subsequent potention radiation doses to the general public can be estimated by the use of an EPA computer code: AIREM (Martin, et al, 1974). In the post mining phase, the potential increased surface flux of radon-222 from reclaimed lands and its consequences on future land use becomes of prime concern.

4.1 Dryer, Storage, and Loadout Emissions

The two rock dryers proposed for the facility are a fluidized bed design. The finer fractions of dry product will exhaust to two cyclone particulate collectors. All particles not collected in the cyclones will be discharged to efficient wet venturi-impingement scrubbers. The scrubber exhausts will discharge through two 18.3 m high stacks to aid dispersion of residual particulate and pollutant gases.

AIREM Assumptions and Inputs: AIREM is a computer code for the calculation of doses to the general population due to atmospheric emissions of radionuclides developed by the Office of Radiation Programs, Environmental Protection Agency (Martin et al., 1974). A standard sector-averaged gaussian-diffusion equation is solved repeatedly for each radionuclide, wind sector, stability class and downwind distance. Radionuclide contributions to doses to critical organs are summed and printed by sector and downwind distance. Radionuclide depositions downwind are calculated.

The input requires wind frequency in percent and wind speed in meters per second for each sector and stability class. The program is written for 6 stability classes. The input meteorological summary must refer to winds blown to a direction. Therefore, the usual meteorological data base must undergo some alteration. The annual National Oceanic and Atmospheric Administrative data for Tampa, Florida, for the period 1/69 through 12/73 (NOAA 1975) was used in this analysis.

The arrays entitled "Annual Relative Frequency Distribution" were reversed in direction, the total fractions were converted to percent, and the percent recorded by stability class for each direction. The percentages in stability class G were added to stability class F, thus eliminating class G data.

The arrays in the NOAA Summary entitled "Annual Frequency Distribution (Speed (KTS))" were converted to meters per second and directions reversed. Speeds for stability class G were weighted into class F by the percent and speed in the two arrays.

Sixteen sectors (22.5°) centered upon the major compass directions were used. Ten segments at radii of 100 meters, 200 meters, 400 meters, 600 meters, 805 meters, 1 mile, 2 miles, 3 miles, 4 miles, 5 miles, and 10 miles were used. Population data were not employed. One person was placed in each sector segment to evaluate the impact. Other imput data and its source is shown in Table 4.1-A.

AIREM Results: The most frequent wind was found to be an east wind blowing to the west. The highest chi/Q value (concentrations per release rate) was observed to be 300 to 500 meters west of the stack which will be between the proposed rail lines and the southeast corner of the clay settling area. Other similar chi/Q values center within plus or

Table 4.1-A Input Data for AIREM Calculations

Item	Value	Source or Reference
Mixing Layer Depth	900 m	Isopleths in AIREM Manual
Rainfall Fraction	0.083	Precipitation Rate: 0.07 in/hr Yearly Rainfall: 50 in.
Washout Coefficient	2×10^{-4} 1/s	(Partridge, et al., 1978)
Deposition Velocity	0.02 cm/sec	W. G. Frank, 2 micron dust particles
Dose Conversion Factors for Lung	Function of Radionuclide (mrem/sec)/(mCi/m^3)	(Partridge, et al., 1978)
Stack Heights	18.3 m 38.1 m 18.3 m	Dryer (Air Quality Resource Document Storage Conservation Consultants, Inc. Loadout 1979)
Particulate Emission Rate (E)	2.889 g/sec 1.100 g/sec 0.728 g/sec	Dryer (Air Quality Resource Document Storage Conservation Consultants, Inc. Loadout 1979)
Operational Time (T)	7446 hrs/yr 8330 hrs/yr 4000 hrs/yr	Dryer (Air Quality Resource Document Storage Conservation Consultants, Inc. Loadout 1979)
Radioactivity Concentrations (C)		
U-238 Series	29 pCi/g	Section 4.8-1
U-235 Series	1.3 pCi/g	Specific Activity Difference Assumed
Th-232 Series	0.3 pCi/g	80% Equilibrium
Po-210	23 pCi/g	
Radionuclide Releases	mCi/yr	(E)x(T)x(C)x Appropriate Conversion Factors

minus 300 meters in the same general direction (WSW to WNW) and again at 500 meters east of the stack within the proposed palnt complex.

Desposition of material from the cloud follows a similar pattern. For example, the ground concentration produced by a year's release of radium-226 at 500 meters west was predicted to be 230 pCi/m^2 from dry deposition and 14 pCi/m^2 from wet desposition. The nearest offsite property is approximately one mile north. Dry deposition at this offsite location to the north of the plant would add approximately 30 pCi/m^2 per year of radium-226 to the soil. Since topsoil has about 0.5 pCi/g and a density of about 1.4 g/cc, the first centimeter of soil will normally contain 7000 pCi/m^2. Thus, the additional depositional radium should not be a measurable quantity.

Lung dose calculations followed the chi/Q pattern with the highest dose rate calculated to be 5.8 mrem/year for continuous exposure at 300 meters west of the plant. One mile north, the lung dose rate offsite drops to 0.4 mrem/yr and at Keentown some 2 miles NNW of the plant the predicted lung dose rate is 0.15 mrem/year. Neither annual dose at these offsite locations can be measured within the statistical variation of natural background. All lung dose rates beyond the one and one-half mile radius are less than 1 mrem/year.

The relative significance of the contributing radionuclides in order of decreasing importance are Ra-226, U-234, Th-230, U-238, Po-210, Th-228, Th-232, U-235 and Th-227. Of the total 17.2 millicuries dispersed each year, fifty-seven percent will remain in the seven and one-half mile radius.

4.2 Radon Flux From Reclaimed Lands

Radon-222 flux from the soil surface will be increased due to the redistribution of radium-226 in the reclaimed lands. Radon in the atmosphere will experience some elevated concentration due to this increased surface flux. The level of radon flux has been considered as an indicator measurement for the potential hazard of indoor radon progeny within slab-on-grade residential and public structures.

Table 4.2-A summarizes predicted radon flux values for various land types of the post-reclamation phase. The first column lists the results of a monolayer diffusion model and the second column contains the values predicted by a bi-layer diffusion model. Specific parameters for each land type were taken from the data of Roessler et.al. (1978) for similar media.

The lower flux values in the second column is due to the addition of two-feet of low-activity topsoil over each land type upon reclamation. In each case the reduction is between twenty and thirty percent. However, all values in the first column are within the range of radon-222 fluxes observed on unaltered lands and reported in Table 6.2-B. The elevation of outdoor airborne radon-226 from these fluxes will not be significant.

5. RECLAIMED LAND USE

The reclaimed lands will have different radiological characteristics than the land before mining. The impact of the new environment depends upon the land use and the levels of various radiological characteristics. Of the many radiation exposure pathways that are possible, three appear to be most directed related to reclamation and land use: (1) working level (WL) elevation in residential structures; (2) uptake of radionuclides into agricultural products, and (3) the impact of

Table 4.2-A Radon Flux Predicted from Reclaimed Lands on the Duette Site

Land Type	Radon-222 Flux, pCi/m^2s Without 2-ft of topsoil	With 2-ft of topsoil
Overburdon Reclaimed	0.75	0.54
Sand/Clay Mixture	0.84	0.60
Tailings Reclaimed	0.46	0.35
Clay Sediments	1.04	0.74
Weighted Average for the site	0.80	0.57

returning lands to natural systems.

5.1 Residential Uses and Working Levels

Of the many land uses considered, the most critical appears to be residential development. This impact must be considered, whether for small numbers of homes in the immediate future or significant numbers in the distant future. Recall that uranium and radium-226 have geological scale half lives.

Indoor radon progeny as measured by Working Level (WL) has been related to increased risk of lung cancer (Fisher, 1978). Since indoor WL measurements are not possible before construction, considerable research effort has gone into pre-construction predictor measurements and the associated correlations. Three land parameters have been considered for prediction of indoor radon progeny: external gamma exposure rate, soil radium, and surface radon flux. The predictor equations given by Roessler et.al. (1978) are:

$$WL = 0.0022\ (G-3.6)^{1.01}$$

$$WL = 0.0065\ (C_{Ra})^{0.563}$$

$$WL = 0.0087\ (J)^{0.461}$$

Where

G = external gamma exposure, μR/hr

C_{Ra} = soil radium-226, pCi/g

And

J = surface radon flux, pCi/m^2s

Table 5.1-A summarizes the predicted indoor radon progeny levels by land type for the Duette site after reclamation.

Table 5.1-A Indoor Radon Progeny by Land Type as Predicted by Various Radiological Parameters

Land Type	Predictor Correlation for Estimated WL		
	Gamma, R/hr vs WL	Ra-226, pCi/g vs WL	Radon-222 Flux pCi/m s vs. WL
Overburden Reclaimed	0.0078	0.0082	0.0076
Sand/Clay Mixture	0.0114	0.0093	0.0080
Tailings Reclaimed	0.0051	0.0065	0.0061
Clay Sediments	0.0229	0.0146	0.0089
Weighted Average for the Site	0.0114	0.0093	0.0078

All values without topsoil in order to present maximum hazard.

It is apparent that the clay area will represent the highest potential hazard, however, this material is one of the least attractive land types for home building because of foundation design problems. Furthermore, reclaimed clay areas only represent some seven percent of the site. Slab-on-grade structures in Polk County over undisturbed lands have Working Levels ranging from 0.001 to 0.010 with a geometric mean of 0.003. Two standards for Working Level in existing homes have been proposed: (1) an HRS standard of 0.029 WL total exposure including background (Fla. 1978) and (2) an EPA standard of 0.020 WL total exposure including background (EPA 1979). The final rulemaking by the State of Florida is expected in the near future. It is anticipated that the "gray" area between normal background and the aforementioned WL standard will be handled on a case-by-case basis with cost versus benefit considerations.

The reclamation processes and undeveloped lands were addressed in detail in EPA's 1979 recommendations to the Govenor of Florida (EPA 1979). Specific guidance for new homes on any reclaimed, debris, and unmined lands which contain phosphate resources integrated both site selection and construction technique:

> "IV. Development sites for new residences should be selected and prepared, and the residences so designed and sited, that the annual average indoor ...." Working Levels "... do not exceed .... background levels...." (EPA 1979)

Normal background and its uncertanties are discussed in the same report.

EPA indicated that "guidance... to aid in evaluation of undeveloped phosphate lands" (EPA 1979) will be forthcoming and that the interim recommendations (EPA 1976) are still appropriate.

If the final guidance for reclaimed lands is similar to the part IV recommendation quoted above, then the upper limit of predicted Working Levels in slab-on-grade homes will be approximately 0.009 WL (normal background of 0.004 WL plus the uncertainty of 0.005 WL). Overall, the Duette site, as reflected in Table 5.1-A, will slightly exceed this upper range. Note, however, that Table 5.1-A was constructed without consideration of the return of any topsoil to the land categories. Either the addition of low activity topsoil to a potential development site or some restrictions in the type of housing construction should mitigate the WL hazard satisfactorily. Only the clay settling areas have the potential for producing homes with greater than 0.02 WL's.

5.2 Agricultural Uses and Uptake

Figure 38.H.3(2) of the Duette DRI indicates the distribution of expected land use after reclamation. Some 68 percent of the land is expected to be improved pasture and a very small percentage (less than 5) may be used for citrus and row crops. The scientific literature contains little information on the potential for crop uptake of radium-226. Most literature data suffers from the lack of companion information on other nutrients in the soil and in the crops. Table 5.2-A indicates the general level of radium-226 in food products of the USA.

The return of any low activity topsoil to reclaimed areas will substantially reduce any potential impact. The most important pathway to

Table 5.2-A Radium-226 in Other Food Products
(After Fiesenne & Keller, 1970)

Diet Item	Radium-226 pCi/g
Fresh Vegetables	0.0016
Root Vegetables	0.0012
Whole Grain Prod.	0.0027
Rice	0.0033
Eggs	0.0140

consider is the direct uptake by row crops grown on the reclaimed clay. Here the radium-226 content is the highest and land will be suited for this productive use. Little is known about the behavior of radium-226 uptake from this type of soil

The order to evaluate the uptake potential of reclaimed clays, limited study was undertaken. Two squash crops were located: one of reclaimed clays and one on undisturbed lands. Squash samples and the soil were analyzed for radium-226. The results are shown in Table 5.2-B. In addition, available nutrient data were obtained. For this one sample set the higher activity soil produced the lower activity in the squash. These findings may be explained by the following theory:

> Higher levels of radium-226 would normally be expected in the squash grown on the soil having the higher radium-226. However, the plant uptake potential is for divalent cations and the reclaimed clay has excess Ca++ and Mg++. Thus, the Ra++ (minute chemical quantities) is diluted and discriminated against.

An interesting calculation can be made with the available data. The site ratio of the distribution of radium between the squash and the soil is by the expression:

$$\frac{\text{Undisturbed: } [\text{Ra-squash}]/[\text{Ra-soil}]}{\text{Reclaimed: } [\text{Ra-squash}]/[\text{Ra-soil}]}$$

and has a value of 2X10'. While the same ratio for the distribution of major cations between the squash and the soil is given by the expression:

$$\frac{\text{Undisturbed: } [\text{Ca + Mg - squash}]/[\text{Ca + Mg - soil}]}{\text{Reclaimed: } [\text{Ca + Mg - squash}]/[\text{Ca + Mg - soil}]}$$

if the Ca and Mg concentrations are assumed be approximately equal in the squash from both sites, then the expression has a value of 1X10'.

Table 5.2-B Uptake of Radium-226 by Squash on Clay Reclaimed and Undisturbed Lands

Land Type	Radium-226, pCi/g		Available Nutrients #/AC	
	Squash	Soil	CaO	MgO
Undisturbed Soil	0.0072	0.17	600	100
Reclaimed Clay	0.0024	13.00	5600	2600

The small acreage involved, the lower radium-226 levels, and the expected land use distribution combine to suggest that the impact of any agricultural uptake pathway will be insignificant. Since current fertilizer products such as TSP may contain up to 32 pCi/g radium-226, the direct application of fertilizer products to crops may be much more important than direct uptake from the reclaimed soil being farmed.

5.3 Natural Systems

The Duette DRI indicates that over one quarter of the land will be reclaimed as forest, freshwater marsh, freshwater swamp, lakes and wilderness. Uranium and radium-226 in these environments is not expected to have any impact or the development of the natural ecosystems. In fact, the developing environments are expected to favor retention of the radioactive species. Water-borne transport will be discussed under the appropriate catagory: Surface or Groundwater.

6. PRODUCT RADIOACTIVITY

It was shown in Section 2. that the finished products are expected to have between 21 and 31 pCi/g of radium-226 and uranium. The offsite shipment will be 62 million tons of phosphate rock at these concentrations. Approximately 1.6×10^{15} pCi of radium-226 and 5400 tons of uranium will be exported offsite. The secondary impacts of these materials will depend upon the location of any additional processing, the final product and its end use. The uranium may be lost as a resource. Spalding and Sackett (1971) have attributed elevated levels of uranium and daughter radioactivity in portions of the Gulf of Mexico to run-off of fertilizer originating in the Mississippi Valley.

7. WATER QUALITY

Radioactivity represents one of many water quality parameters. Public concern, the unique physical and chemical characteristics, and the long-term hazard potential are some features of radioactivity in water that suggest separate evaluation. Groundwater and surface waters represent the two major pathways of transport to man and each will be discussed separately.

Section 15 of the Duette DRI addresses the existing water resources and water quality parameters. The water uses, recycles and discharges are outlined in Sections 38.C and 38.D of the Duette DRI. Of the many radioactive species that are potentially involved in water contamination, radium-226 is the most hazardous, although concern has been expressed for evaluation of radium-228 and uranium.

The important guidelines for concentrations of radioactivity in water are the drinking water regulations (EPA 75) and the effluent limitations for the phosphate industry (EPA 74). Community water systems shall not exceed 15 pCi/l of gross alpha activity (including radium-226 but excluding radon and uranium). The combined radium-226 and radium-228 in drinking water shall not exceed 5 pCi/l. The drinking water regulations recognize less stringent analysis options for those areas where thorium and thus radium-228 is considerably below the national average. The EPA has established an effluent guideline for the phosphate industry of 9 pCi/l of radium-226.

7.1 Surface Water Quality

Section 2.9.6.1 has reviewed the status of surface water radioactivity in the USA, the State, the phosphate mining district, and the proposed mine site. Three factors appear to migate the impact of

radioactivity upon surface waters in the phosphate district.

a) The critical nature of water resources encourages a high degree of recycle of water within the process systems.

b) The important radioactivity species, like radium-226, are extremely insoluble under many environmental conditions, and

c) any treatment of waste-waters for other water quality parameters has an inherent high efficiency for radioactive species in the same water.

Mills et.al (1977) have reviewed the benefication process with respect to radioactivity in water. If findings and conclusions of that study are adjusted to the ratio of radioactivity of currently mined central Florida matrix to that of the Duette site, the following conclusions are evident:

a) most of the waste product radioactivity will be present in the clay entrained water. For the Duette site this amounts to approximately 8000 gpm of water at a radium-226 concentration of <2 pCi/l (dissolved) and <50 pCi/l (undissolved). The latter value is highly dependent upon the total suspended solids in the clay wastes, and

b) although no chemical processes are used to treat the discharge from clay settling areas, the concentration of radium-226 is normally <1 pCi/l due to removal of suspended solids by settling and the incorporation of some dissolved material in the settling floc.

The working paper on the Radiation Environment for the areawide impact assessment program (Texas Instruments, 1977) states that "it is obvious that releases of slime-pond decant water will have little radiation impact on the environment". The various controls on water releases and the lower radioactivity in the matrix make this statement even more valid for the Duette site.

The accident situation has been considered by the Florida State Department of Health and Rehabilitative Servies (1975) in a calculation of the radiological health consequences of a hypothetical slime-pond dike failure using the Becker Phosphate Corporation DRI as a model.

Using extreme conditions, the dose to an individual drinking the accidentally contaminated water for one year would not exceed 31 mrem. Realistic values in the accident model would reduce the dose from a single accident by one to two orders of magnitude.

The extreme insolubility of radium-226 is suggested by a number of factors. First, the secular equilibrium of uranium-238 and radium-226 in the numerous core samples reveal that differential dissolution in the natural state has not taken place over the time scale of radium-226 re-equilibration times (8000 years). Secondly, the beneficiation process itself is an extreme oportunity for leaching and should lead to fraction of the radium-226 from the minerals if radium-226 were not so insoluble. Thirdly, there has been no reports of widespread surface water contamination with these radioactive species in runoff from the existing mining and reclaimed areas in west central Florida. Lastly, limited data from the Occidental Chemical Co., EIS (EPA 1978) and the Hookers Prairie, DRI (Geraghty and Miller, 1978) suggest a distribution coefficient (pCi/g solid phase per pCi/ml liquid phase) of between 10^3 to 10^4. This implies that reclaimed lands having soil radium-226 concentrations of as high as 2 pCi/g would yield an equilibrium concentrations of radium-226 in contacted water of no greater than 0.2 to 2 pCi/l. These values would tend to be further diluted by runoff from areas having less radium-226 in the soil and by waters from other sources. These theories suggest that the radiological impact from the post-reclamation phase upon surface waters will be limited.

7.2 Groundwater Quality

The baseline data for radioactivity has been reviewed in Section 2.9.6.2. Some of the same conclusions stated for radioactivity in surface water (recycle uses, species insolubility, and high removal efficiencies) are

just as valid for reducing the potential for groundwater contamination.

The areawide impact statement for the industry (EPA 1978) postulated two primary effects for groundwater and one secondary impact in the "without action" scenario:

Primary:

" • local water-table quality deterioration because of draining and dewatering, overburden, product storage, seepage from contaminated ponds and reclamation of mining pits.

• local Floridan aquifer water-quality deterioration from waste-water injection."

Secondary:

" • possible contamination of groundwaters by seepage of process waters at the chemical plants and slime-pond waters in the mine areas."

The data available, however, did not support any direct recomendation in the proposed action section, except that connector wells recharge water should meet recommended drinking water criteria chemically, bacteriologically, and radiologically at all times. The Duette site connector well and recharge program is addressed in a report included in the Addendum to the Duette DRI. Water quality sampling in both the initial and test phases of the program has included radioactivity. The initial conclusion is that the shallow aquifer water should be acceptable for recharge to the Floridan aquifer.

Although not specifically stated, an analysis of the areawide impact statement and other site specific DRI's and EIS's clearly indicate that whenever other water quality parameters are within acceptable

limits the radioactive species will be within acceptable limits. Or stated another way, radioactivity has not been observed to be the critical water quality criteria.

The importance of the gamma logs of deep wells and their indication of rather large sources of radioactivity in other strata has been addressed in section 2.9.3.2. The relationship of this radioactivity in deep strata to observed radioactivity in deep aquifers was discussed in section 2.9.6.2. It is important to reemphasize that any existing radium-226 in groundwaters, especially in the Floridan aquifer, may have a variety of sources and the most likely source is the naturally occurring radium-226 in the lower Hawthorn. This fact also makes it exceedingly difficult to "trace" radium-226 to it's source, since nearly all materials and strata contain measureable quantities.

There is some evidence for the higher radium-226 level in the deep aquifers to be associated with very poor quality water (i.e. high Na^+ or Cl^-). Excessive drawdown of the aquifer has the potential for producing salinity intrusion into good quality aquifers. Whether radium-226 follows the intrusion or disolution is prompted by the higher salinity is not known. Sound management of water resources to avoid this phenomena by any extreme withdrawals is recommended.

8. SUMMARY

The radiological impacts of the proposed Duette mine , it's beneficiation process and other activities are as follows:

Matrix Radioactivity - Radium-226 (9 pCi/g) in the matrix, some forty feet below the surface, will be mined and partionated into waste clays (4 pCi/g), sand tailings (1 pCi/g), product pebble (29 pCi/g) and product concentrate (24 pCi/g).

Subsurface Radioactivity - Pre-mining radium-226 profiles (<1 pCi/g at the surface to 18 pCi/g near the matrix) will be altered to a reclaimed profiles having from between 1 and 4 pCi/g nearly unformally distributed with depth.

Occupational Exposures - The highest potential for occupation exposure would be in loading tunnels unless thay are ventilated and occupancy times restricted.

Terrestrial Gamma Radiation - The mean outdoor gamma radiation of the site is expected to increase from 5.1 μR/hr to 8.8 μR/hr.

Airborne Radioactivity - Dryer and other emisions are expected to deposit over half of the radioactivity within a radius of seven and one-half miles. The yearly desposition (pCi/m^2 per year) beyond one mile would not increase the radioactivity of the soil to any measurable degree.

Lung dose calculations indicate the highest dose rate for continuous exposure to be 6 mrem/yr at 300 meters west of the stack. All lung dose rates for continuous exposure beyond 1½ mile are less than 1 mrem/yr.

Radon flux from the soil surfaces of the site are expected to increase from a baseline of 0.2 pCi/m^2s to less than 0.8 pCi/m^2s.

Elevation of outdoor airborne radon-226 is not expected to be measurable.

Land Use Criteria - Residential development for the site is not expected within the immediate future. For any homes that are constructed, the predicted indoor radon progeny (WL) could range from 0.005 WL (tailings reclaimed) to 0.023 WL (clay settling areas).

Agricultural development of the site is not predicted to pose an radiological impact from the limited soil-to-crop-to man food chain uptake.

Natural ecosystem development will not be affected by the increased radioactivity and may inhance retention of the radioactivity.

Surface Water Radioactivity - Surface water radium-226 concentrations in off-site environs may be elevated from natural levels of <0.8 pCi/l to <2 pCi/l. By comparison, the drinking water standard for radium-226 is 5 pCi/l and the discharge guideline for the industry is 9 pCi/l.

Groundwater Radioactivity - The groundwater radium-226 concentrations at the site are less than those observed in non-mining regions. Radium-226 in groundwaters appears to be associated with local subsurface environments.

The connector wells for recharge of the Floridan aquifer represent a potential transport mechanism for radioactivity. However, monitoring of the more basic water quality parameters should prevent contamination by radioactivity.

PART I

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